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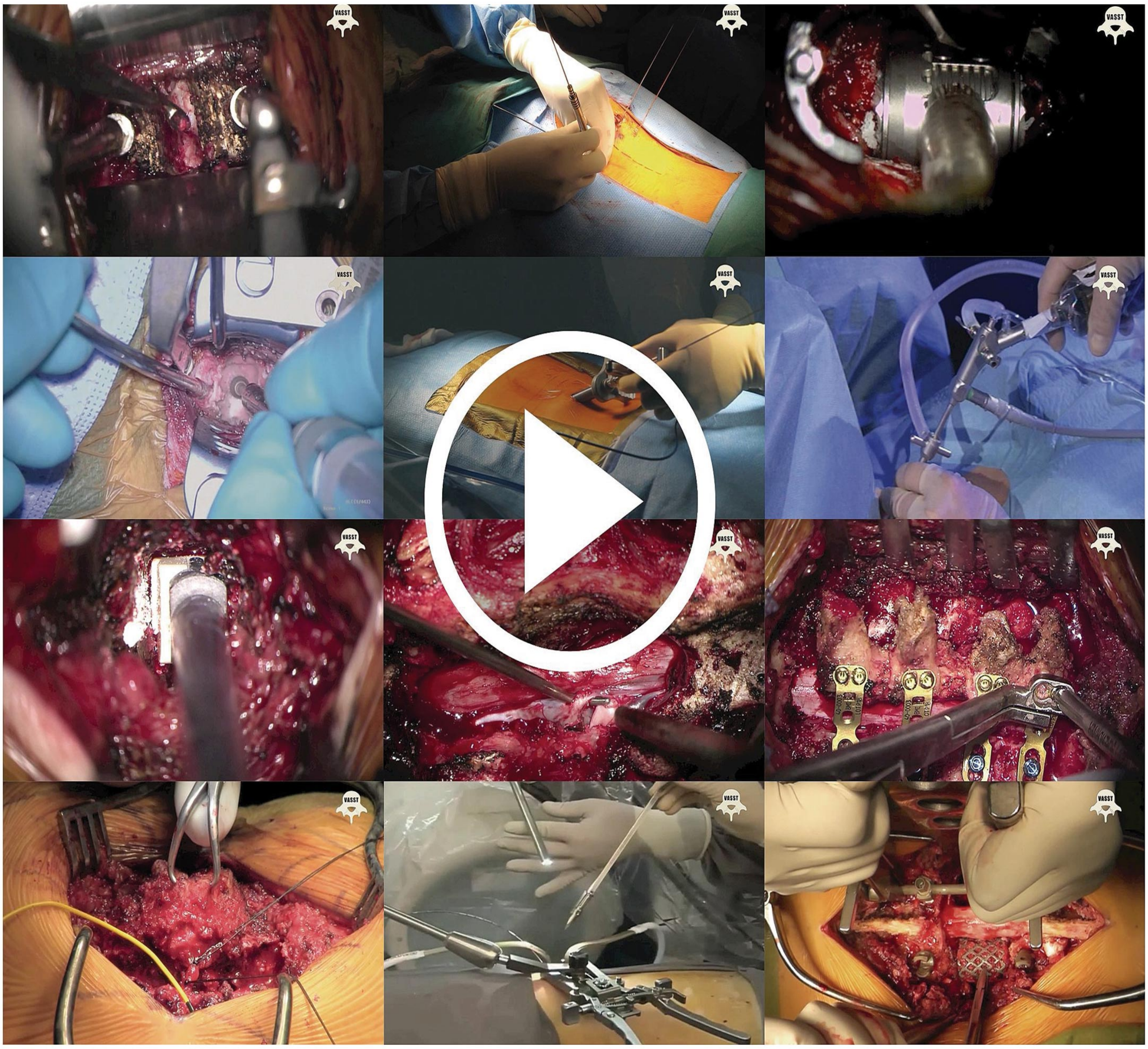
VOLUME 2



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Federico Landriel & Eduardo Vecchi

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Frontiers in Neurosurgery

(Volume 2)

Video Atlas of Spine Surgical Techniques

Edited By

Federico Landriel
&
Eduardo Vecchi
Department of Neurosurgery
Hospital Italiano
Buenos Aires
Argentina

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Department of Neurological Surgery - Case Western Reserve University School of Medicine - MetroHealth Medical Center - Cleveland, OH - USA

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Department of Neurosurgery - Mansoura University School of Medicine – Mansoura - Egypt

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Department of Neurosurgery - Rush University Medical Center - Chicago, IL - USA

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FOREWORD

The ***Video Atlas of Spine Surgical Techniques*** edited by Federico Landriel and Eduardo Vecchi is certainly a strikingly original contribution to surgical education.

Continuing education in medicine or surgery is mandatory and it's also a requirement of the Society, Courses, Congresses, Symposiums and many other forms of education are carried on with this purpose nowadays.

One possible solution for the present and the future are the new Technologies of Information and Communication (TIC's) to “e-Learning” and the goal is to achieve a comprehensive vision of the different techniques as well as the necessary training for a proper surgical practice.

Indeed these young colleagues, who I appreciate and admire, are definitely the right people to lead a laborious task as the publication of this essential atlas. With the best people worldwide they have given birth to an original work, which undoubtedly represents a milestone showing the most modern surgical techniques in spine surgery.

It is a work primarily dedicated to the education of our young colleagues but also to those who want to be updated on all the techniques related to surgical pathology of the spine.

I'm sure that this original e-atlas will have the best welcome within the neurosurgical community because it fills a gap in the methodology of Neurosurgical Education globally.

Armando Basso, MD, PhD.
Emeritus Professor Buenos Aires University Hon.
President of the World Federation of Neurosurgical Societies
Buenos Aires
Argentina

PREFACE

The *Video Atlas of Spine Surgical Techniques* e-book includes 3-to-8-minute subtitled HD videos of the most salient spine operations as performed by an international renowned topic experts surgeons, and a detailed description of surgical indications, preoperative planning, patient positioning, surgical technique, complications, postoperative care, outcome and surgical pearls with full-color images and illustrations highlighting the different key stages of each technique presented as a book chapter.

One of the main assets of this video e-atlas is the possibility of using it as a learning resource on a portable computer, tablet, smartphone or any other device equipped with a display. Thanks to its electronic format, it is an easy to download resource available for use 24/7 all year round for anyone with Internet access.

The purpose of this atlas is to illustrate on video a broad range of spinal surgical procedures. We believe this will be of interest to both the novice and the experienced spinal surgeon, as it will help enhance their skills. The high-quality videos provides a detailed visual guidance on the relevant anatomy involved as well as crucial details concerning the surgical procedure, that would pass unnoticed in a photograph-based format, allowing the development of skills in the correct surgical timing and steps. Additionally, it offers different perspectives by experts on the field aimed at improving performance and avoiding complications.

Federico Landriel & Eduardo Vecchi
Department of Neurosurgery
Hospital Italiano
Buenos Aires
Argentina

DEDICATION

This book is dedicated to my parents, Marisa and Enrique, and brothers, Pablo and Rodrigo, whose continuing encouragement and understanding provided so much support during my childhood and first years of career.

To my teachers Eduardo Vecchi and Antonio Carrizo, who initiated me in Neurosurgery and Spine surgery.

This book could not have been completed without the continuing help and patience of my loving wife, Guly, who is my most loyal supporter and advisor. As my companion and mother of our two lovely daughters, Emilia and Catalina, she is the cornerstone of my life and of our wonderful family.

Federico Landriel

To my Teachers, Dr. Pierre Grunewald and Dr. Pierre Galibert, with whom I began in Spinal Pathology. To my colleague and friend, Dr. Jorge Shilton, with whom, at countless Meetings, Congresses, Courses, Chapters, Workshops, we humbly tried to raise awareness on the fact that Spinal Pathology is also part of Neurosurgery, and that there was still much to develop. Finally, to my unconditional loved ones, my daughters Belén, Agustina and Luciana, and to my lifetime partner, my support, Dina.

Eduardo Vecchi

List of Contributors

Ajler P, MD, PhD.	Assistant Professor - Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina
Astur N, MD.	Pediatric Spine Fellow, Campbell Clinic Orthopedics, Memphis, TN - USA Department of Orthopedics and Traumatology, Santa Casa de São Paulo School of Medicine and Hospitals, São Paulo, SP - Brazil
Awad BI, MD.	Spine Fellow - Department of Neurological Surgery, Case Western Reserve University School of Medicine - MetroHealth Medical Center - Cleveland, OH, USA Department of Neurological Surgery, Mansoura University School of Medicine, Mansoura, Egypt
Beccaceci F, MD.	Resident Physician - Department of Neurosurgery, Military Hospital, Mendoza, Argentina
Begun EM, BS.	Research Assistant - Department of Neurosurgery, William Beaumont Hospital, Royal Oak, Michigan, USA
Beltrame S, MD.	Resident Physician - Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina
Belzberg A, MD.	Associate Professor of Neurological Surgery - Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA
Bendersky D, MD.	Resident Physician - Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina
Benzel EC, MD.	Chairman, Professor of Surgery - Department of Neurosurgery, Neurological Institute, Center for Spine Health - Cleveland Clinic - Cleveland, OH, USA
Berbeo Calderón ME, MD.	Neuroscience Department Director, San Ignacio University Hospital, Javeriana School of Medicine, Bogotá, Colombia Hospital Universitario, Bogotá, Colombia
Bozinov O, MD.	Staff Neurosurgeon, Resident Program Director - Department of Neurosurgery, University Hospital Zurich, Switzerland
Branch CL Jr. MD.	Professor and Chair - Department of Neurosurgery, Wake Forest Baptist Medical Center., Winston Salem, New York, USA
Brotchi J, PhD, FACS.	Emeritus Professor and Chairman - Department of Neurosurgery, Erasme Academic Hospital, Brussels, Belgium
Burkhardt JK, MD.	Staff Neurosurgeon - Department of Neurosurgery, University Hospital Zurich, Switzerland

Bydon A, MD.	Associate Professor of Neurosurgery - Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA
Bydon M, MD.	Resident Physician, PGY6 - Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA
Calcagni E, MD.	Director and Chairman - Orthopedic Department, Centro Medico Rivera, Buenos Aires, Argentina Orthopedic Department, Centro de Estudio de las Enfermedades de la Columna Vertebral (CEECV), Buenos Aires, Argentina
Carrizo AG, MD, PhD.	Professor of Neurosurgery - Department of Neurosurgery, Hospital Italiano de Buenos Aires, Argentina
Cassini F, MD.	Staff Neurosurgeon - Department of Neurosurgery, Spine Division - Clínica Güemes, Luján, Buenos Aires, Argentina
Chen KS, MD.	Resident Physician - Department of Neurosurgery, University of Michigan, Ann Arbor, Michigan, USA
Cremaschi F, MD.	Head Professor of Clinical Neurology and Neurological Surgery - Vice Dean, National University of Cuyo, School of Medicine, Mendoza, Argentina
Cruz Bravo M, MD.	Resident Physician - Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina
Dahdaleh NS, MD.	Assistant Professor of Neurosurgery, Minimally Invasive and Complex Spine, Northwestern University Feinberg School of Medicine, Chicago, IL, USA
Dawes B, MBBS (Hons) DipAnat.	Department of Neurosurgery, Austin Health - University of Melbourne, Australia
DeCuypere M, MD, PhD.	Resident Physician - Department of Neurosurgery, University of Tennessee, Memphis, TN - USA
Deutsch H, MD.	Associate Professor - Department of Neurosurgery, Rush University Medical Center, Chicago, IL, USA
Diaz RC, MD.	Assistant Professor of Neurosurgery. Neurosurgical Department Chief, Ignacio University Hospital, Javeriana School of Medicine, Bogotá, Colombia
Du R, MD, PhD.	Assistant Professor - Department of Neurosurgery, Brigham and Women's Hospital - Harvard Medical School, Boston, Massachusetts, USA
El Ahmadieh TY, MD.	Post-doctoral Research Fellow - Northwestern University - Department of Neurological Surgery, Northwestern University, Chicago, IL - USA
Erbulut DU, PhD.	Departments of Mechanical Engineering and Neurosurgery, Koc University, Istanbul, Turkey

Fernandez J, MD.	Chief of Neurosurgery - Regional One Health, Trauma Center, Memphis, TN - USA Department of Neurosurgery, University of Tennessee, Memphis, TN Semmes-Murphey Neurologic & Spine Institute, Memphis, TN
Fernández M, MD.	Chief Resident - Department of Neurosurgery, Military Hospital, Buenos Aires, Argentina
Fernández Molina F, MD.	Medical Resident, Division of Neurosurgery, University Hospital, Buenos Aires University, Buenos Aires, Argentina
Fessler RG, MD, PhD.	Professor - Department of Neurosurgery, Rush University Medical Center, Chicago, IL - USA
Fierstra J, MD, PhD.	Resident Physician - Department of Neurosurgery, University Hospital Zurich, Switzerland
Gala N, MD.	Resident Physician - Department of Neurosurgery, Allegheny General Hospital, Pittsburg, Pennsylvania, USA
Garategui L, MD.	Chief Resident - Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina
Ghobrial GM, MD.	Resident Physician - Department of Neurological Surgery, Thomas Jefferson University Hospital, Philadelphia, PA, USA
Gokaslan Z, MD.	Donlin M. Long - Professor of Neurosurgery, Oncology, and Orthopaedic Surgery - Vice Chairman, Department of Neurosurgery - Director, Neurosurgical Spine Program -Director, Neurosurgical Spine Metastasis Center. Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA
Goldschmidt E, MD, PhD.	Chief Resident - Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina
González Abbati S, MD.	Head, Cranial Base Section, Division of Neurosurgery, University Hospital, Buenos Aires University, Buenos Aires, Argentina
Gonzalvo A, MD, FRACS.	Director of Neurosurgery - Austin Health, University of Melbourne, Australia
Gore SR, MD, MS.	Orthopedics - Consultant Endoscopic Spine Surgeon, Prime Surgical Center, Pune, MS - India
Gutierrez R, MD.	Staff Neurosurgeon - Department of Neurosurgery, Clínica Güemes, Luján, Buenos Aires, Argentina
Hamade YJ, MD.	Post-doctoral Research Fellow - Northwestern University - Department of Neurological Surgery, Northwestern University, Chicago, IL - USA
Harrop JS, MD.	Professor - Department of Neurological Surgery, Thomas Jefferson University Hospital, Philadelphia, PA - USA

Hellinger S, MD	Consultant Orthopaedic Department, ISAR Klinik, Munich, Germany
Hem S, MD.	Neurosurgeon - Department of Neurosurgery, Spine Division, Hospital Italiano, Buenos Aires, Argentina
Hilibrand AS, MD.	Associate Professor - Department of Orthopedic Surgery, The Rothman Institute - Thomas Jefferson University Hospital, Philadelphia, PA - USA
Hong JT, MD, PhD.	Professor - Department of Neurosurgery, St. Vincent's Hospital, Catholic University, Korea
Hwang SW, MD.	Assistant Professor - Department of Neurosurgery, Tufts Medical Center and Tufts University School of Medicine, Boston, Massachusetts, USA
Jalón P, MD.	Head, Spine Section, Division of Neurosurgery, University Hospital, Buenos Aires University, Buenos Aires, Argentina
Jho DH, MD, PhD.	Assistant Professor - Department of Neurosurgery, Allegheny General Hospital, Pittsburg, Pennsylvania, USA Neuroendoscopy, Chairman, Professor of Neurosurgery - Department of Neurosurgery, Allegheny General Hospital, Pittsburg, Pennsylvania, USA
Kahn EN, MD.	Resident Physician - Department of Neurosurgery, University of Michigan, Ann Arbor, Michigan, USA
Khurana A, MBBS, MS, MRCS, MSC, FRCS (Tr & Orth).	Consultant Orthopaedic & Spinal Surgeon, Aneurin Bevan University Health Board, New Port, South Wales, UK
Kim IS, MD, PhD.	Associate Professor - Department of Neurosurgery, St. Vincent's Hospital, Catholic University, Korea
Kim JY, MD.	Fellow - Department of Neurosurgery, St. Vincent's Hospital, Catholic University, Korea
Kim MS, MD.	Fellow - Department of Neurosurgery, St. Vincent's Hospital, Catholic University, Korea
Klimo P Jr. MD, MPH.	Chief of Pediatric Neurosurgery - Department of Neurosurgery, University of Tennessee, Memphis, TN Semmes-Murphey Neurologic & Spine Institute, Memphis, TN Le Bonheur Children's Hospital, Memphis, TN - USA
La Marca F, MD.	Associate Professor - Department of Neurosurgery, University of Michigan, Ann Arbor, Michigan, USA
Landriel F, MD.	Neurosurgeon - Resident coordinator. Department of Neurosurgery - Spine Division, Hospital Italiano, Buenos Aires, Argentina
Li Y, MD.	Resident Physician - Department of Neurological Surgery, University of Wisconsin Medical School, Madison, WI – USA

Lin J, BA.	Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA
Macki M, BS.	Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA
Marchi L, MS.	Clinical Study Coordinator, Instituto de Patología da Coluna (IPC), São Paulo, Brazil
Mendoza-Torres J, MD.	Spine Fellow - Department of Neurosurgery, Oakland University William Beaumont, School of Medicine, Royal Oak, Michigan, USA
Mercado Santori A, MD.	Chief of Neurosurgery Department - Spine Surgery, Military Hospital, Mendoza, Argentina
Mezzadri JJ, MD, PhD.	Head, Division of Neurosurgery, University Hospital, Buenos Aires University, Buenos Aires, Argentina
Miltos C, MD.	Chief of Neurosurgery Department, Hospital Central del Instituto de Previsión Social, Asunción, Paraguay
Mouminah AS, MBBS.	Research Fellow - Department of Neurosurgery, Brigham and Women's Hospital - Harvard Medical School, Boston, Massachusetts, USA
Msaddi AK, MD.	Professor - Head of Neurosurgical and Spinal Department - Medical Director, Neuro Spinal Hospital, Dubai, UAE
Muhlbauer MS, MD.	Staff Neurosurgeon - University of Tennessee, Department of Neurosurgery, Memphis, TN Semmes-Murphey Neurologic & Spine Institute, Memphis, TN Le Bonheur Children's Hospital, Memphis, TN - USA
Murakami H, MD, PhD.	Associate Professor - Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kanazawa University, Ishikawa, Japan
Neal MT, MD.	Chief Resident of Neurosurgery - Wake Forest Baptist Medical Center, Winston Salem, New York, USA
Nicolas M, MD.	Thoracic Surgeon - General Surgery, Hospital Italiano, Buenos Aires, Argentina
Oppenlander ME, MD.	Resident Physician - Division of Neurological Surgery, Barrow Neurological Institute - St. Joseph's Hospital and Medical Center, Phoenix, Arizona, USA
Ozer AF, MD.	Professor - Department of Neurosurgery, Koc University School of Medicine , Istanbul, Turkey
Papademetriou K, BS.	Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA

Parihar V, MBBSS, MS, MCh, DNB.	Assistant Professor - Department of Neurosurgery, NSCB Governmental Medical College, Jabalpur, India
Park P, MD.	Associate Professor - Department of Neurosurgery, University of Michigan, Ann Arbor, Michigan, USA
Perez-Cruet M, MD, MS.	Professor and Vice-Chairman - Department of Neurosurgery, Oakland University William Beaumont, School of Medicine, Royal Oak - Michigan, USA
Perin NI, MD, FRCS (Ed) FAANS.	Associate Professor - Department of Neurosurgery, NYU Langone Medical Center, New York, USA
Pimenta L, MD, PhD.	Assistant Professor - Department of Neurosurgery, UCSD San Diego, California, USA Instituto de Patología da Coluna (IPC), São Paulo, Brazil
Prasad SK, MD.	Associate Professor - Department of Neurological Surgery, Thomas Jefferson University Hospital, Philadelphia, PA - USA
Prina JR, MD.	Chairman - Department of Neurosurgery, Clínica Güemes, Luján, Buenos Aires, Argentina
Qiu Y, MD.	Professor - Department of Spine Surgery, Drum Tower Hospital, Nanjing University Medical School, Jiangsu, China
Quinteros M, MD.	Staff Neurosurgeon - Department of Neurosurgery, Clínica Güemes, Luján, Buenos Aires, Argentina
Quraishi NA, LLM FRCS (Tr & Orth).	Consultant Spine Surgeon - Centre for Spinal Studies and Surgery - Queens Medical Centre Campus of Nottingham, University Hospitals NHS Trust, Nottingham, UK
Rasmussen J, MD.	Resident Physician - Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina
Ratre S, MBBS, MS, MCh.	Assistant Professor - Department of Neurosurgery, NSCB Governmental Medical College, Jabalpur, India
Resnick DK, MD, MS.	Professor and Vice Chairman, Residency Program Director, Co-Director, Spinal Surgery Program - President, Congress of Neurological Surgeons – Director, research Council, North American Spine Society – Past Chair, AANS/CNS Joint Section on Disorders of the Spine - Department of Neurological Surgery, University of Wisconsin School of Medicine and Public Health, Madison, WI, USA
Richter B, MD.	Resident Physician - Department of Neurosurgery, Allegheny General Hospital, Pittsburg, Pennsylvania, USA
Riesenburger RI, MD.	Assistant Professor - Department of Neurosurgery, Tufts Medical Center and Floating Hospital for Children - Tufts University School of Medicine, Boston, Massachusetts, USA

Rodriguez A, MD, PhD.	Resident Physician - Department of Neurosurgery, Wake Forest Baptist Medical Center.,
Ropper AE, MD, PhD, FRCP.	Resident Physician - Department of Neurosurgery, Brigham and Women's Hospital - Harvard Medical School, Boston, Massachusetts, USA
Rubino P, MD.	Staff Neurosurgeon - Department of Neurosurgery, Hospital de Alta Complejidad “El Cruce”, Florencio Varela - Buenos Aires, Argentina
Safain MG, MD.	Resident Physician - Department of Neurosurgery, Tufts Medical Center and Tufts University School of Medicine, Boston, Massachusetts, USA
Samdani AF, MD.	Chief of Spine Surgery - Department of Neurosurgery, Shriners Hospitals for Children, Philadelphia, USA
Sarnthein J, PhD.	Neurophysiologist - Department of Neurosurgery, University Hospital Zurich, Switzerland
Sarramea H, MD.	Director and Chairman - Orthopedic Department, Centro de Estudio de las Enfermedades de la Columna Vertebral (CEECV), Buenos Aires, Argentina
Shafafy M, MBBS, FRCP (Tr & Orth).	Consultant Spine Surgeon - Centre for Spinal Studies and Surgery - Queens Medical Centre Campus of Nottingham, University Hospitals NHS Trust, Nottingham, UK
Shinmura K, MD.	Staff Physician - Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kanazawa University, Ishikawa , Japan
Smith D, MD.	Chairman Thoracic Surgery Section - General Surgery, Hospital Italiano, Buenos Aires, Argentina
Smith ZA, MD.	Assistant Professor of Neurosurgery, Minimally Invasive and Complex Spine, Northwestern University Feinberg School of Medicine, Chicago, IL, USA
Steinmetz MP, MD.	Chairman, Associate Professor - Department of Neurological Surgery, Case Western Reserve University School of Medicine - MetroHealth Medical Center, Cleveland, OH, USA
Syed HR, MD.	Resident Physician - Department of Neurosurgery, Medstar Georgetown University Hospital, Washington, USA
Takagi I, MD.	Attending Neurosurgeon - Legacy Spine and Neurological Specialists, Little Rock, Arkansas, USA
Tan KD, MD.	Chief Resident - Department of Neurosurgery, University of Michigan, Ann Arbor, Michigan, USA
Tan LA	Resident Physician - Department of Neurosurgery, Rush University Medical Center, Chicago, IL, USA

Tecle NE, MD, MS.	Post-doctoral Research Fellow - Department of Neurological Surgery, Northwestern University, Chicago, IL, USA
Tedesco N, MD.	Chief Resident - Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina
Toscano M, MD.	Resident Physician - Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina
Tsuchiya H, MD, PhD.	Professor - Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kanazawa University, Ishikawa, Japan
Vecchi E, MD.	Assistant Professor - Vice-Chairman Department of Neurosurgery, Chairman Spine Division - Hospital Italiano, Buenos Aires, Argentina
Voyadzis JM, MD, FAANS.	Assistant Professor - Department of Neurosurgery, Medstar Georgetown University Hospital, Washington, USA
Wang AC, MD.	Chief Resident - Department of Neurosurgery, University of Michigan, Ann Arbor, Michigan, USA
Warner Jr. WC, MD.	Professor - Campbell Clinic Orthopaedics, Memphis, TN - USA
Weingart J, MD.	Professor of Neurosurgery - Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA
Wolinsky JP, MD.	Associate Professor of Neurosurgery - Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA
Wong AP, MD.	Neurosurgery Fellow, Minimally Invasive and Complex Spine, Northwestern University, Feinberg School of Medicine, Chicago, IL, USA
Yadav YR, MBBS, MS, MCh.	Associate Professor and Head of Department of Neurosurgery, NSCB Governmental Medical College, Jabalpur, India
Yampolsky CM, MD.	Chairman - Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina
Yañez A, MD.	Chief of Pediatric Neurosurgery - Hospital Pedro de Elizalde - Staff Neurosurgeon - Department of Neurosurgery, Spine Division - Clínica Güemes, Luján, Buenos Aires, Argentina
Yeung AT, MD.	Orthopedic Spine Surgeon, Voluntary Professor - Department of Neurosurgery, University of New Mexico School of Medicine - Albuquerque, New Mexico - Desert Institute of Spine Care, Phoenix, Arizona, USA
Ypa P, MD.	Chief of Residents - Division of Neurosurgery, University Hospital, Buenos Aires University, Buenos Aires, Argentina
Zammar SG, MD.	Post-doctoral Research Fellow - Northwestern University - Department of Neurological Surgery, Northwestern University, Chicago, IL, USA
Zhu Z, MD.	Associate Professor - Department of Spine Surgery, Drum Tower Hospital, Nanjing University Medical School, Jiangsu, China

SECTION I- CERVICAL SPINE

Occipitocervical Fusion

Federico Landriel*, Eduardo Vecchi, Santiago Hem

Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina

Keywords: Craniocervical junction, Occipitocervical fusion, Occipitocervical fusion HD video, Surgical video OC fusion.

GENERAL ASPECTS

The craniocervical junction is a transition area between the rigid cranium and the mobile cervical spine that includes the brainstem and the spinal cord. This area accomplishes greater than 50% of all head and neck movements, motion that complicates the surgical achievement of stability. Occipitocervical fusion may be indicated for multiple atlantooccipital and atlantoaxial instability processes. Several fusion techniques have been used, including bone grafts, wiring, pin fixation, hooks, plates and hybrids constructs. Current rigid fixation techniques with cervical polyaxial screws connected to a plate fixed to the occiput *via* contoured rods have demonstrated, superior relief of cervical pain, better correction of malalignment, lower rate of postoperative adverse events and instrumentation failure compared with less rigid wiring techniques [1 - 4].

INDICATIONS

Radiographic criteria for craniocervical instability due to:

- Congenital deformities
- Cranial settling
- Iatrogenic
- Osteomyelitis/ bone destruction/ instability of kyphotic deformity
- Rheumatoid arthritis
- Trauma

* **Address correspondence to Federico Landriel:** Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina; E-mail: fedelandriel@gmail.com

- Tumor

CONTRAINDICATIONS

- Occipital craniectomy defects involving the target fixation site
- Severe occipital bone fractures

SURGICAL TECHNIQUE

In case of severe stenosis, fiberoptic intubation should be considered to minimize the risk of hyperextension spinal cord injury. Somatosensory-evoked potential (SSEP) and motor-evoked potential (MEP) baseline signals are monitored. The patient is placed in prone position with rolls under the chest and iliac crests to avoid abdominal compression, thus decreasing venous bleeding. The head is fixed with a three-point pin head holder. The neck is slightly flexed to improve surgical field; extreme flexion must be avoided as it may produce spinal cord ischemia. A more neutral alignment should be performed prior to the final instrumentation placement and tightening. The table is tilted cranially upward about 15° degrees. After the patient is positioned, lateral and anteroposterior fluoroscopy are performed to confirm satisfactory alignment.

A midline skin incision is made from the external occipital protuberance to the spinous process of the lowest level to be included in the construct. The fascia is opened in T-shape, leaving a remnant of tissue attached to the occipital bone for closure reconstruction. This ensures that the occipital plate and screws will be entirely covered by muscle, thus reducing the possibility of hardware eroding trough the skin. Subperiosteal dissection is preformed with monopolar cautery exposing the suboccipital bone and dorsal elements of the cervical spine.

Decompression, if necessary, is performed. In this case we fix a patient with atlantoaxial instability and anterior displacement of the occiput and atlas with respect to the axis. The posterior C1 arch is exposed without exceeding 15 mm laterally on the cephalad aspect, thus avoiding vertebral artery injury. It can be thinned with a high-speed drill and removed or resected in block to save bone for autograft. In this case we also perform a suboccipital decompression.

For cervical screw fixation, it is our preference to use C1 lateral mass screws, C2 transpedicular screws, or if preoperative studies demonstrate narrow pedicles we consider C2 translaminar screws. If subaxial construct extension is necessary, we use lateral mass screw fixation. We review preoperative imaging to assess the vertebral arteries anatomy, course and lateral dominance if any.

For C1 screw fixation the lateral mass of C1 at the C1-C2 joint is exposed, the venous plexus surrounding the C2 nerve root can bleed and hemostasis could be achieved with bipolar cautery and/or hemostatic agents. The inferior third of the C1 posterior arch is removed with a burr to expose the screw entry point at the center of the lateral mass; this removal improves drill and screw placement angle. The C2 nerve is mobilized caudally or sectioned with excision of the dorsal root ganglion; this maneuver increases lateral mass exposition. The entry point is decorticated with a matchstick burr, the drill bit medial angulation trajectory is usually 10°. On lateral fluoroscopic imaging the drill trajectory is aimed toward the anterior tubercle of C1.

The tip of the drill should stop between the posterior edge and middle of the anterior tubercle of C1, thus avoiding drilling into the posterior pharynx. Our preference is to use a width of 3.5-mm screws with a length range of 30 to 36 mm. Larger screws allow for the polyaxial head to be placed superficial to the C2 nerve root avoiding its mechanical compression. In example case due to C1 displacement over C2, the lateral masses of C1 were difficult to expose (Fig. **1**).

The entry point of C2 pedicle screw is at the top of the pars, approximately 5 mm superior and 5 mm lateral the inferior medial aspect of the inferior articular surface of C2 (Fig. **2**). The medial border of the pedicle is palpated to help guide the trajectory and avoid medial cortical breach into the neural canal (Fig. **3**). Extreme lateral placement can violate the transverse foramen and injure the vertebral artery. The trajectory requires a medial angulation of approximately 20° to 30° and an upward trajectory of 20° to 25° [5] (Figs. **4** and **5**).

We only extend the construct with subaxial lateral mass screws if the placement of screws in C1 or C2 is anatomically unfeasible or screw purchase poor.

CHAPTER 2

Occipitocervical Chiari Decompression

Federico Landriel[*], Eduardo Vecchi, Santiago Hem, Lucas Garategui, Pablo Ajler

Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina

Keywords: Chiari Malformation Video chapter, Chiari Surgery, Occipitocervical Chiari HD video, Surgical Video Chiari decompression.

GENERAL ASPECTS

Chiari malformation involves a group of conditions with disruption of normal cerebrospinal fluid flow through the foramen magnum and abnormalities in the posterior fossa and the craniocervical junction.

In the type I, the cerebellar tonsils are caudally displaced through the foramen magnum generally down to the ring of C1. The diagnostic image study of choice is MRI, which must show a tonsilar herniation below the foramen magnum of at least 5 mm and crowding of the cerebrospinal fluid (CSF) spaces in the craniocervical junction. Other image findings include hydrocephalus, compression of fourth ventricle, basilar invagination, syringobulbia and syringomyelia. In symptomatic patients, the gold standard treatment is early surgery and the main goal is to remove the compression of the brainstem and reestablish the CSF flow at the craniocervical junction.

INDICATIONS

Surgery is indicated in the presence of symptoms or signs. The most common are the suboccipital headache and neck pain that is worsened with Valsalva maneuvers. Numbness or weakness of one or more limbs is frequent. Some patients also complain of ocular disturbances, diplopia, blurred vision, retro-orbital pain, dizziness and ear pressure. Lower cranial nerve, cerebellar and

[*] **Address correspondence to Federico Landriel:** Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina; E-mail: fedelandriel@gmail.com

brainstem findings could be present. Signs of spinal cord dysfunction are frequent if syringomyelia is present (hyperactive lower limbs reflexes, paresthesia, gait disturbances, burning dysesthesias, weakness, spasticity, incontinence, atrophy, etc). 15-30% of patient's meeting radiographic diagnostic criteria are asymptomatic [1]. Patients who are asymptomatic or symptomatic and stable for years could be observed.

SURGICAL TECHNIQUE

In case of severe stenosis, fiberoptic intubation should be considered to minimize the risk of hyperextension spinal cord injury. Somatosensory-evoked potential (SSEP) and motor-evoked potential (MEP) baseline signals are monitored. The patient is placed in prone position with rolls under the chest and iliac crests to avoid abdominal compression thus reducing operative blood loss. The head is fixed with a three-point pin head holder. The neck is slightly flexed to improve surgical field; extreme flexion must be avoided as it may produce spinal cord ischemia. The table is tilted cranially upward about 15° degrees.

A midline skin incision is made from the inion to C2-3 spinous process. The fascia is opened in T-shape, leaving a remnant of tissue attached to the occipital bone for closure reconstruction. The nuchal ligament is dissected slightly paramedian with monopolar cautery, than with sharp dissection, the half part of the nuchal ligament is resected, to be used later, as an autologous path graft for enlargement of the posterior fossa and craniocervical dura.

The posterior C1 arch is exposed without exceeding 15 mm laterally, thus avoiding vertebral artery injury. The area of the occipital craniectomy is planned to be as wide as the foramen magnum and 25 mm cranio-caudal to avoid cerebellar herniation. The suboccipital decompressive craniectomy is performed with a high-speed drill and Kerrison rongeurs. The posterior C1 arch is thinned and removed.

The posterior atlanto-occipital ligament is divided, and the dura is opened with a Y-shaped incision, beginning below the probable location of the circular sinus. The dura is tented with track-up sutures to prevent the inflow of blood into the subdural space. The arachnoid is opened with microscissors. Cerebellar tonsils are released to expose the floor of the 4th ventricle.

The graft patch, harvested from the nuchal ligament, is sewn to the dura with 3.0 non-absorbable sutures (Figs. **1** and **2**).

Fig. (1). Intraoperative photograph shows nuchal ligament graft patch.

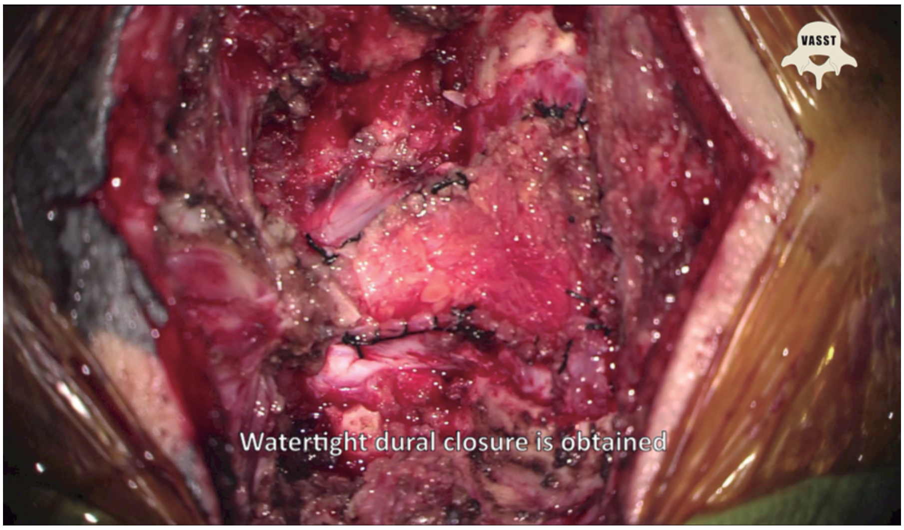

Fig. (2). Intraoperative photograph shows the graft patch sewn to the dura with 3.0 non-absorbable sutures.

The Valsalva maneuver is routinely performed to assess watertight dural closure. After irrigating the surgical field with sterile water, the muscles, fascia,

CHAPTER 3

Endoscopic Chiari Decompression

David H. Jho*, Nihar Gala, Hae-Dong Jho

Department of Neurosurgery, Allegheny, General Hospital, Pittsburg, Pennsylvania, USA

Keywords: Chiari decompression, Chiari malformation video, Endoscopic, Suboccipital craniectomy.

INDICATIONS AND CONTRAINDICATIONS

The indications for Endoscopic Chiari Decompression (ECD) are similar to standard Chiari decompression using the microscope, including tussive headaches and compressive symptoms at the cervicomedullary junction. Typically, the cerebellar tonsils extend ≥5 mm below to the foramen magnum with Chiari type-1 malformation. MRI sagittal sequences will show the degree of inferior extent of the cerebellar tonsils along with possible syrinx, and MRI axial sequences will show the degree of crowding of the foramen magnum region and the cervicomedullary junction. Incidental Chiari type-1 malformations that do not have any symptoms, brainstem compression, or significant syrinx are managed conservatively. ECD is a safe alternative to standard microscopic Chiari decompression in appropriately selected patients, and has been demonstrated with endoscope-assisted and purely endoscopic versions of the procedures [1 - 3].

Relative contraindications include morbid obesity with excessive posterior neck adipose tissue and other anatomic considerations.

SURGICAL TECHNIQUE

The patient is placed in a prone position on chest rolls with a 3-point head holder and slight neck flexion. Either a 1.5-cm trocar is used for the working port (with the length of the plastic port trimmed to customized depth as needed) or slim profile self-retaining retractors may be used. We use the Unitrac® endoscope

* **Correspondence to David H. Jho:** Department of Neurosurgery, Allegheny, General Hospital, Pittsburg, Pennsylvania, USA, E-mail: davidjho1@gmail.com

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holder (Aesculap) and 4-mm rod-lens endoscope with 0° angle and 18-cm length (Karl Storz) with cleansing device. Alternatively, a microscope can be used but may not always provide the same quality of close-up views through a small working area. The operating surgeon usually stands at the head of the bed with an inverted view of the operating field but may instead stand superior-lateral to the patient if the inverted view is disorienting.

A midline vertical incision <3 cm in length is made at the cranial-cervical junction, with suboccipital decompression and C1 laminectomy done in most cases. We typically do not perform tonsillar resection and make a simple midline dural incision with duraplasty, as illustrated in the video for case #1. When there is extensive descent of the cerebellar tonsils or large syrinx, rarely C2 laminectomy be also required, but the same skin incision entry site can be used with dynamic angulation of the working pathway as needed to reach the C2 target. For extensive syrinx, a syringo-subarachnoid shunt is occasionally used to facilitate drainage and resolution of the syrinx through a small midline myelotomy, as shown in the video for case #2. A 4-mm diamond drill bit is used to perform the bone drilling with periodic irrigation, and the suboccipital craniectomy is usually done to at least a 1-cm extent but may be customized to the patient's pathology. The C1 laminectomy is done to ~0.5-cm extent bilaterally from the midline with drilling, with additional lateral drilling done after visualization of the epidural space and spinal canal, and hand instruments such as Kerrison rongeurs are used to complete the decompression of the spinal canal.

The posterior atlanto-occipital or craniocervical ligamentous band against the posterior dura is divided sharply at the midline and removed using Kerrison rongeurs. The dura is opened with a midline vertical incision, and the cerebellar tonsils are visualized. The arachnoid layer may be maintained or dissected, depending on the surgeon's preference and individual pathology. A dural graft of the surgeon's choice can be used, with the graft edges tucked inside the edges of the native dura to allow for a ball-valve effect in an outward direction to minimize the risk of cerebrospinal fluid (CSF) leak. We typically use bovine pericardium or other dura graft of similar consistency and thickness to allow good eventual healing at the junction of the graft and native dura. The dural graft can be closed circumferentially in a watertight fashion using anchoring sutures followed by running suture closure in an unlocked or locked fashion. As an alternative, the dural graft can be closed in a watertight fashion using anchoring sutures followed by fine titanium surgical clips, as shown in the video.

After irrigation of the surgical field, and after testing of the watertight dural closure with Valsalva maneuver, the incision is closed in layers with watertight closure of the fascia layer in standard fashion. The subcutaneous layer along with the skin layers are closed with interrupted buried, absorbable sutures, and the skin is covered with BioGlue such as Dermabond® or with Steri-strips®. Typically, the suboccipital craniectomy and C1 laminectomy with duraplasty is sufficient to treat most cases of Chiari type-1 malformation, without any additional dissection of arachnoid adhesions, neural tissue manipulation, obex drainage, or resection of cerebellar tonsils [4]. However, additional components of the procedure may be customized for the extent of pathology in the individual patient [5]. For a large significant syrinx as shown in the video for case #2, we occasionally perform a small midline dorsal myelotomy for access to the syrinx with intraoperative decompression of the dilated spinal cord and, in rare cases, placement of a syringo-subarachnoid shunt can be done with customization for the patient's individual pathology.

COMPLICATIONS

Potential complications include CSF leak, cerebellar or brainstem injury, spinal cord injury, and vascular injury, such as the posterior inferior cerebellar artery (PICA) or vertebral artery. The risk of CSF leak is minimized by the following measures:

1. Using a graft that has similar thickness and consistency to the native dura, which will heal together well at the junction.
2. Tucking the edges of the graft inside the edges of the native dura as an inlay graft to allow ball-valve effect in the desirable outward direction
3. Closure of the dura with sutures having needle circumference no larger in diameter than the suture itself so that there is no CSF seepage through the suture holes or, alternatively, with permanent clips as shown in the video.
4. Closure of the fascia in a watertight fashion as an additional barrier to any

CHAPTER 4

Endoscopic Transoral Odontoidectomy

Yad Ram Yadav*, Vijay Parihar, Shailendra Ratre

Department of Neurosurgery, NSCB Governmental Medical College, Jabalpur MP, India

Keywords: Endoscopic odontoidectomy, Odontoidectomy video, Odontoidectomy technique, Endoscopic transoral surgery.

GENERAL ASPECTS

Although transoral microscopic resection is the most common surgical approach for irreducible atlantoaxial dislocation (AAD), there are reports of endoscopic transoral techniques [1 - 8] in this condition. Endoscopic procedures for spine and brain pathologies including AAD have been increasingly performed safely and effectively in recent times [9, 10]. Endoscopic transoral excision of the odontoid has been found to be safe, effective and minimally invasive technique which is direct [1 - 8].

INDICATIONS AND CONTRAINDICATIONS

Although most of the AAD can be reduced by pre operative traction, endoscopic transoral technique is indicated in irreducible AAD. This is defined when the dislocation does not reduce after traction. It is contraindicated in mobile AAD.

SURGICAL TECHNIQUE

Slight extension (Fig. **1**) of the neck is preferred, although neutral position can be used. The tongue is retracted by means of a Dingman retractor. Although a 4-mm, 0-degree endoscope is used in most of the procedure, 30-degree scope is helpful to see at the corners of the field. 0- degree scope should be placed in center of the surgical field, whereas 30-degree scope is positioned in the corner of the operative area.

* **Correspondence to Yad Ram Yadav:** Department of Neurosurgery, NSCB Governmental Medical College, Jabalpur MP, India; E-mail: yadavyr@yahoo.co.in

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Fig. (1). Image shows neck extension using sandbag under the shoulder and head ring.

30-cm long endoscope is better than the 18-cm one as the camera and light source cables are kept away from the instruments used in surgery (Fig. **2**).

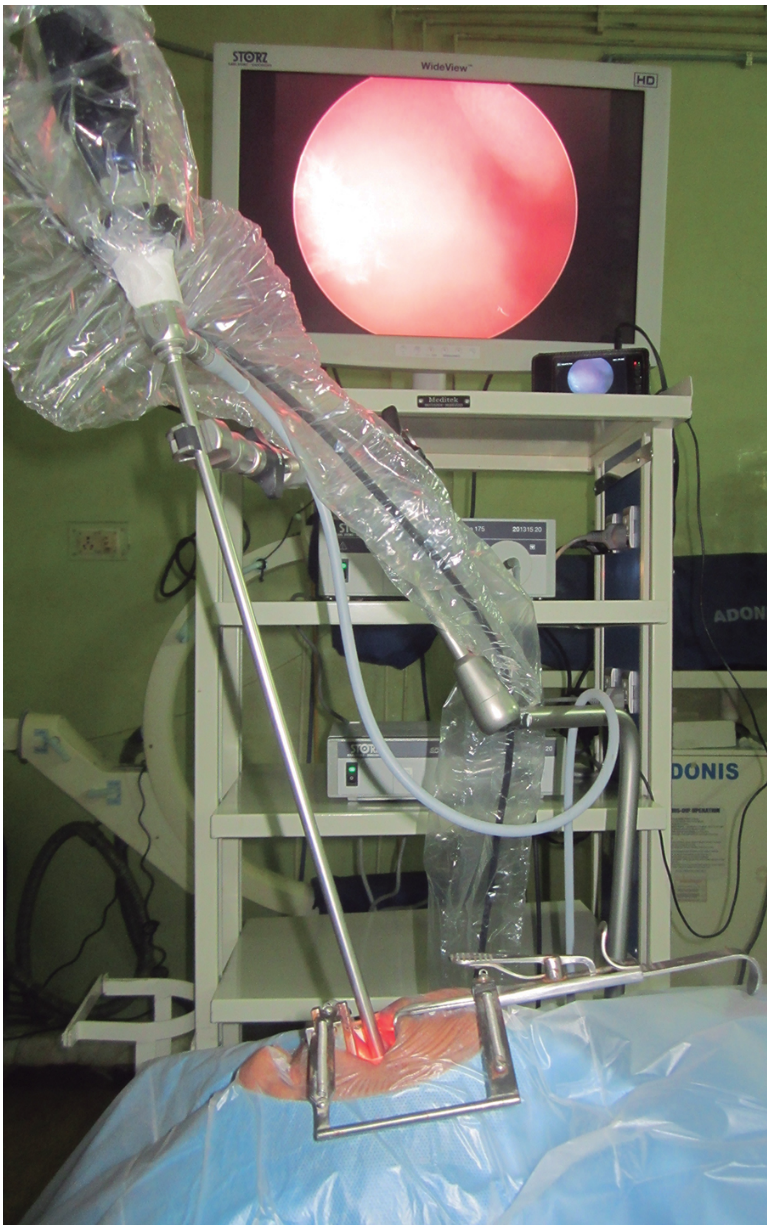

Fig. (2). 30-cm long, zero-degree endoscope is placed in the centre of the surgical field. 30-cm long scope is better than the 18-cm one as the camera and light source cable are kept away from the instruments used in surgery.

CHAPTER 5

Odontoid Screw Fixation

Michael DeCuypere[*, 1], Julius Fernandez[1,2,4], Paul Klimo, Jr.[1,2,3]

[1] *University of Tennessee, Department of Neurosurgery, Memphis, TN, USA*

[2] *Semmes-Murphey Neurologic & Spine Institute, Memphis, TN, USA*

[3] *Le Bonheur Children's Hospital, Memphis, TN, USA*

[4] *Regional One Health, Memphis, TN, USA*

Keywords: Odontoid fracture video, Type II - Odontoid screw fixation, C1-2 instability technique.

GENERAL ASPECTS

Fractures of the odontoid process account for 5%-15% of all traumatic injuries to the cervical spine. Fractures at the base of the odontoid process (type II) are the most common odontoid injury and require close inspection of the integrity of the atlantoaxial complex, as this would allow for abnormal movement that may lead to immediate or delayed catastrophic spinal cord injury [1]. Conservative measures such as immobilization in a rigid brace or halo vest may carry high morbidity in certain populations and has significant and well-documented failure rates [2 - 5]. Several internal fixation methods have been described to treat acute type II and shallow/non-communitued type III fractures. Posterior instrumentation and fusion of C1-2 may restrict axial rotation as much as 50% [6]. In contrast, the direct anterior screw fixation technique provides immediate fracture reduction and stability, preservation of atlantoaxial motion, and high rates of healing with acute fractures [7].

The odontoid screw fixation procedure requires thorough preoperative planning, careful patient selection and well-orchestrated surgical technique. The following chapter will review the complete surgical management of a patient with an acute type II odontoid fracture (Figs. **1** and **2**).

* **Address correspondence to Michael DeCuypere:** University of Tennessee, Department of Neurosurgery, Memphis, TN, USA; E-mail: mdecuype@uthsc.edu

Federico Landriel and Eduardo Vecchi (Eds)

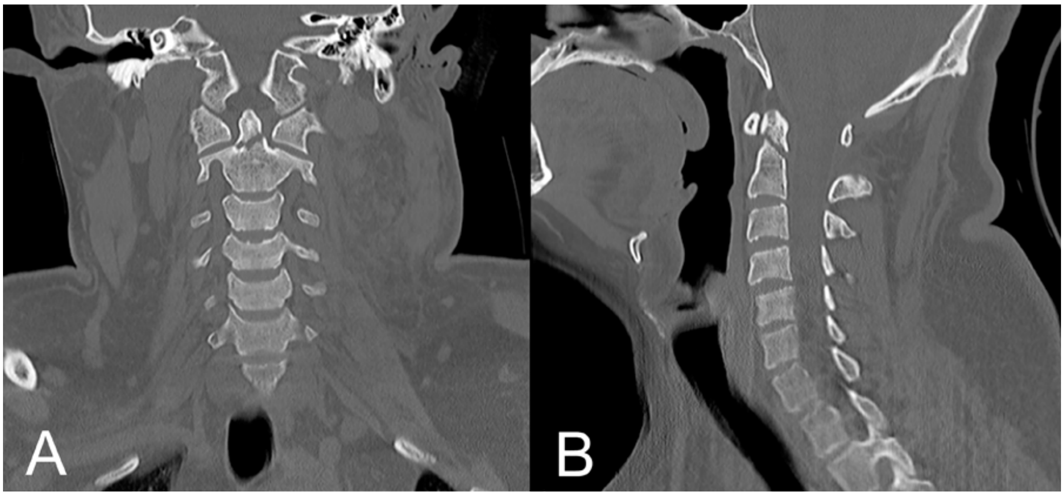

Fig. (1). Coronal (A) and sagittal (B) CT images of a patient with an acute type II posterior oblique odontoid fracture. Note the >10 degrees fracture angulation.

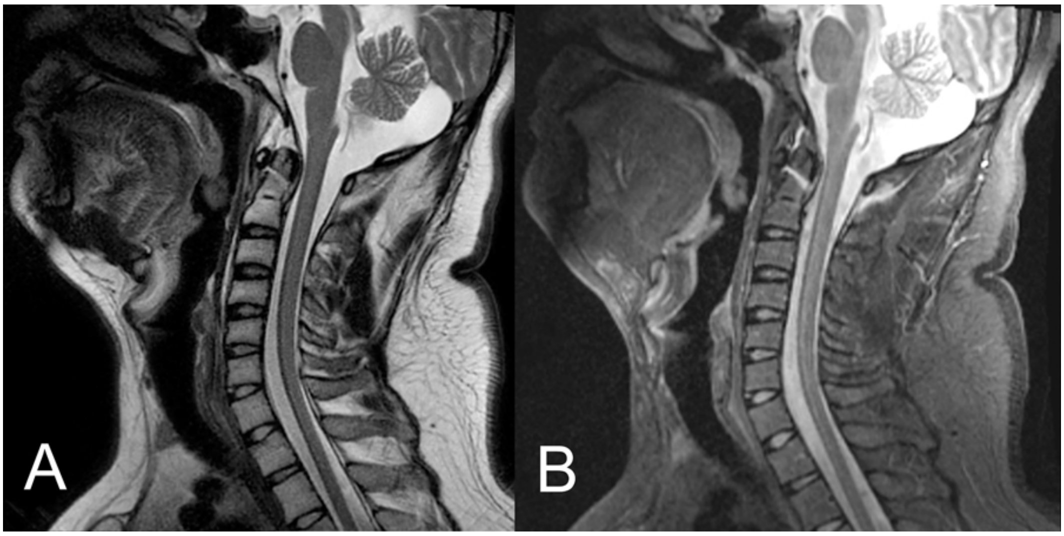

Fig. (2). Sagittal T2 weighted (A) and STIR (B) MRI images of the acute type II odontoid fracture. Note the hyperintensity within the fracture line on the STIR sequence.

INDICATIONS

- Anterior screw fixation is indicated in type II fracture patterns that portend a high rate of nonunion (initial displacement >4 mm, posterior displacement, fracture angulation >10°, delay in diagnosis >3 weeks, patient age >40 years) and in some patients, such as the elderly or demented, who cannot tolerate a halo vest orthosis [8].

- Because of high nonunion rates, some surgeons recommend primary internal fixation for shallow type III fractures, which may behave more like type II injuries.
- Surgery also avoids significant halo vest-related morbidity, such as pin site infection, skin breakdown, facet joint stiffness and skull perforation that may lead to suppurative intracranial complications. Surgery may also decrease in-hospital mortality in elderly patients who would otherwise be treated with orthosis [9, 10].

CONTRAINDICATIONS

- Anatomical closed reduction of the odontoid fracture is imperative; inability to reduce the fracture is an absolute contraindication for direct anterior screw fixation.
- Relative contraindications to anterior screw fixation include transverse atlantal ligament disruption, chronic fracture, and the so-called anterior oblique fracture (extending from an anteroinferior to posterosuperior direction) that may lead to odontoid fragment shearing anteriorly during lag compression, with subsequent translation of C1 on C2.
- Physical characteristics that interfere with the ideal trajectory include short neck, concomitant thoracic kyphosis, barrel chest deformity, and fractures that require a flexed position to obtain reduction [11].
- An odontoid fracture associated with comminuted atlantoaxial joints (one or both).
- An atypical type II fracture with an oblique fracture line involving the caudal-anterior portion of C2. This leaves only a small piece of the C2 body available for interfragmentary compression.
- Pathological fracture or severe osteopenia.

SURGICAL TECHNIQUE

Planning and Positioning

- Pre-surgical planning and positioning is absolutely critical for optimal screw placement. At our institution, general endotracheal anesthesia is usually induced

CHAPTER 6

Anterior Cervical Foraminotomy

David H. Jho*, Bertram Richter, Hae-Dong Jho

Department of Neurosurgery, Allegheny, General Hospital, Pittsburg, Pennsylvania, USA

Keywords: Anterior cervical decompression, Anterior foraminotomy video, Endoscopic anterior foraminotomy, Foraminotomy surgical technique.

INDICATIONS AND CONTRAINDICATIONS

Endoscopic anterior foraminotomy (EAF) is performed for radiculopathy associated with foraminal stenosis, to decompress specific nerve roots [1, 2]. EAF can be done without spinal cord decompression (SCD), as illustrated in the video.

EAF with SCD involves additional decompression of the anterior compressive pathology at the spinal canal for central stenosis, and indications include myelopathy [3 - 5]. Incidental central stenosis is a controversial indication for any decompressive cervical spine surgery, and patient´s preferences are taken into account for conservative *versus* surgical management options. There is usually little controversy if there are overt signs of spinal cord injury such as myelopathic signs or spinal cord signal change on MRI. Foraminal and central stenosis are most commonly caused by spondylosis, degenerative disc disease, herniated discs, and disc-osteophyte complexes, but can be caused by other compressive pathologies such as ossification of the posterior longitudinal ligament (OPLL) or ventral extradural tumors such as meningiomas. EAF with SCD approach can also be used for selected ventral extradural tumors in the subaxial cervical spine [6]. Morbid obesity with short thick neck anatomy, multiple previous neck surgeries, neck radiation, and other anatomic limitations are relative contraindications.

SURGICAL TECHNIQUE

The patient is supine with shoulder roll and head in neutral position. We use the

* **Address correspondence to David H. Jho:** Department of Neurosurgery, Allegheny, General Hospital, Pittsburg, Pennsylvania, USA; E-mail: davidjho1@gmail.com

Federico Landriel and Eduardo Vecchi (Eds)

Unitrac endoscope holder (Aesculap) and 4-mm rod-lens endoscope with 0(angle and 18-cm length (Karl Storz) with cleansing device. Alternatively, a microscope can be used but may not always provide the same quality of close-up views. Transverse skin incision is made, and the platysma muscle layer is dissected transversely or vertically depending on surgeon's preference. The loose areolar tissue plane medial to the sternocleidomastoid muscle (SCM) sheath is dissected, medial to the carotid artery complex and lateral to the tracheo-pharyngeal-esophageal complex, towards the uncinate and transverse processes.

A hand-held retractor is used during development of this plane, and the longus colli muscles along with the target uncinate process and adjacent transverse processes are palpable through the prevertebral fascia. The anterior tubercle of the C6 transverse process (Chassaignac or carotid tubercle) is the most inferior palpable process and can be used to assist localization. Using scissors and bipolar electrocautery, the longus colli fascia and muscle are split longitudinally, and self-retaining retractors are placed with hemostat on the medial longus colli with intraoperative X-ray for localization. After confirming the correct target level, 1.5-mm diamond drill bit is used to drill the lateral portion of the uncinate process. Depending on the angle of approach and trajectory, a direct transunchal approach may be used, *versus* an upper or lower vertebral approach [7, 8].

The foraminotomy usually measures approximately 2-mm width and 8-mm height, providing an anterior-medial decompression area for the nerve root. For EAF with SCD, the foraminotomy can be expanded to approximately 4-mm width and 8-mm height to allow for sufficient decompression with curettes in the spinal canal, as a foraminoplasty approach [7, 8]. After entering the epidural space, Penfield microdissectors, micropituitary forceps, Kerrison rongeurs, and a variety of curettes are used to complete the foraminotomy (and SCD if needed). Epidural veins can be controlled with hemostatic agents or by bipolar cautery on low settings. The surgical site is then irrigated, and the platysma and skin layers are closed with absorbable sutures.

COMPLICATIONS

Potential complications can include neck hematoma, neuropraxia, nerve root or spinal cord injury, cerebrospinal fluid (CSF) leak, discitis, hypopharynx or esophageal injury, recurrent laryngeal nerve injury, Horner's syndrome, spinal instability, and spontaneous bony fusion. As regards to spinal instability, EAF can be approached for individual patients with the amount of potential bony removal being considered a continuous spectrum, similar to bony removal in other spine surgeries such as dorsolateral foraminotomies and laminectomies. The C5 nerve root tends to be the most sensitive to neuropraxia, as with other cervical spine surgeries, and nerve manipulation should be minimized especially at the C5 root. Rarely, dural rent or tear can result in CSF leak, but this does not typically lead to potential nerve root herniation as in the lumbar spine region due to the straighter paths of the cervical nerve roots, and to the fact that CSF leak can potentially resolve with an inlay dural graft. The risk of partial Horner's syndrome is highest at inferior levels such as C6-C7 due to the anatomy of the sympathetic plexus. This risk can be minimized by making the window through the longus colli fascia with Metzenbaum scissors and reserving bipolar cautery for within the muscle rather than on the fascia surface where the sympathetic plexus runs. Cases of Horner's syndrome include partial ipsilateral eyelid droop immediately postop, and typically resolve on their own over months.

POSTOPERATIVE MANAGEMENT

EAF takes approximately 1-hour per level with overnight hospital stay and does not require postoperative immobilization, with routine discharge home on postoperative day one.

OUTCOMES

In a review of 104 patients, there was complete resolution of symptoms in ~80%, with partial improvement in ~19%, and only modest improvement in ~1% [2]. As with many types of spine surgeries, optimizing the accuracy of localizing symptoms and diagnosis along with individual patient selection can result in overall excellent outcomes.

KEY TECHNICAL POINTS

- Anterior bony osteophytes and hypertrophied uncinate processes can distort

CHAPTER 7

Anterior Cervical Disectomy

Federico Landriel*, Eduardo Vecchi, Santiago Hem, Michael Cruz Bravo, Antonio Carrizo

Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina

Keywords: ACDF HD video, Surgical Video ACDF, Anterior Cervical Discectomy.

GENERAL ASPECTS

Anterior cervical discectomy with fusion (ACDF) is one of the surgical procedures of choice for the treatment of cervical disc disease. Autogenous iliac crest bone grafts (AICGs) for cervical arthrodesis have been considered as the treatment option for decades but numerous complications have been reportedly associated with the donor site. To prevent these complications, heterologous grafts, allografts, and synthetic interbody cages have been developed with different materials as a substitute for AICGs with comparable outcomes [1].

INDICATIONS

- Herniated nucleus pulposus causing persistent or recurrent radiculopathy unresponsive to conservative treatment.
- Compressive myelopathy.
- Progressive neurologic deficit.
- Cervical spondylosis with radiculopathy or myelopathy.
- Ossification of the posterior longitudinal ligament (OPPL) with myelopathy in patients without cervical lordosis and with significant kyphosis.
- Non-degenerative etiologies as trauma, infection, malignancy and inflammatory diseases.

* **Address correspondence to Federico Landriel:** Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina; E-mail: fedelandriel@gmail.com

SURGICAL TECHNIQUE

The patient is placed in supine with a small shoulder roll and head foam donut to provide neutral or mild extension position and arms tucked at sides. In patients with severe cervical stenosis or large canal narrowing, a cervical extension test is performed with neurophysiological monitoring before intubation and during positioning. All appropriate pressure points are padded, including the ulnar nerves bilaterally and the heels. Fluoroscopy is used to mark the skin parallel to the involved disc space.

In one-level or two-level discectomy, a transverse incision is performed to be more esthetically pleasing; we prefer the left-sided approach because the recurrent laryngeal nerve follows a more predictable path on this side and injury possibility is decreased. The fascia is opened with monopolar electrocautery; the first muscle encountered is the platysma. Curved scissors are used to dissect bluntly underneath the platysma, using bipolar cautery and scissors, the muscle is transected in line with the incision. The sternocleidomastoid muscle is identified on the anterolateral side of the incision. The blunt dissection proceeds along the anteromedial aspect of the sternocleidomastoid. With finger dissection the medial border of the carotid sheath is separated from the lateral border of the trachea and esophagus; this facilitates the retractors placement.

We use hand-held retractors in 2 or more level discectomies to avoid prolonged compression of the carotid or esophagus; dry cottonoids are used to expose the anterior vertebral body surface. The omohyoid muscle may be encountered crossing in an oblique fashion almost perpendicular to the sternocleidomastoid when exposing the C6 level; if it interposes in the field, it may require division.

A standard needle is placed in the intended operative level and intraoperative fluoroscopy is used again to re-confirm the disc space. The prevertebral fascia is divided with monopolar cautery from medial to lateral where the longus colli muscles are identified. The longus colli muscles are released from the medial attachments and are dissected in a subperiosteal fashion.

All osteophytes are removed with the Cushing rongeur to ensure a flat surface of bone that will ultimately facilitate later plate fixation. An annulotomy in box fashion is performed with a scalpel blade to begin the discectomy. The superficial portion of the disc is removed with a pituitary rongeur. The first part of the disc can be also removed with curettes or Kerrison punches before distraction is necessary. Distraction can be accomplished using pins placed in the adjacent bodies and a Caspar distractor or intervertebral spreaders. Under distraction, the remainder of the disc is removed with curettage of the cartilaginous endplates (Fig. **1**). If an intervertebral spreader is used, it should be placed in the lateral border of the disc space, against the uncus. Distraction with intervertebral spreaders improves visualization and allows better removal of posterior osteophytes. The posterior longitudinal ligaments (PLL) with their longitudinal fibers are identified. After proper decompression the dura is visualized (Fig. **2**). The opening of the PLL is performed to determine if a sequestered fragment is present and achieved adequate decompression of spinal cord and nerve roots. This maneuver also helps to remove posterior osteophytes. The dural plane is now evident.

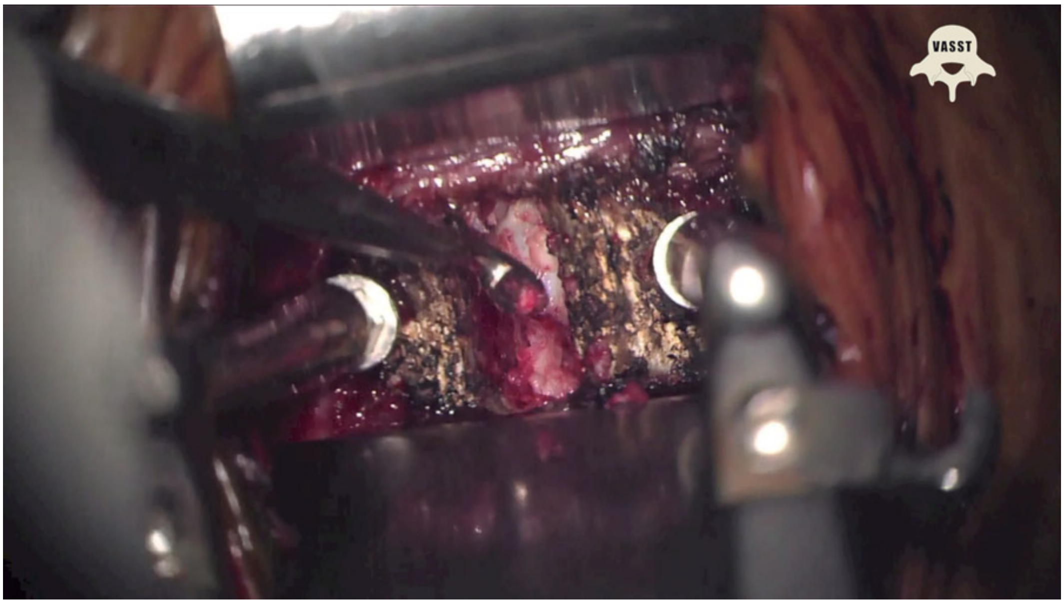

Fig. (1). Intraoperative photograph shows Caspar distractor and the disc removal with curettage of the cartilaginous endplates.

The endplates are partially removed with a ball tip diamond burr to facilitate bony

CHAPTER 8

Selective Percutaneous Endoscopic Cervical Decompression and Discectomy

Stefan Hellinger*

Orthopedic Department, ISAR Klinik, Munich, Germany

Keywords: Endoscopic cervical discectomy video, Endoscopic discectomy technique, Endoscopic surgery, Minimally invasive cervical discectomy.

GENERAL ASPECTS

There is a high incidence of cervical discogenic pain symptoms in the population. The treatment of cervical discogenic diseases makes high demands in terms of both diagnostics and therapy. Diagnostics has been made easier by improved imaging and the enhancement of neurological measuring methods. Consequently, there is now interdisciplinary consensus that the principal pathologic causes can be reliably identified.

The most common cause of cervical pain syndromes is a degenerative change in the intervertebral disc, where disc tissue is displaced, on one hand, and damage occurs in the movement segment, on the other hand. Displacement of disc tissue to the epidural space may give rise to a biochemical lesion [1], vascular compression and mechanical compression of neural structures. This results in pain in the neck and head region, radiating into the arm, and also autonomic symptoms or even neurologic disorders. Other causes of disc-related pain are to be found in the dorsal annulus fibrosus, the posterior spinal ligament and the periosteum of the vertebral bodies, where there are active pain receptors. In the final analysis, the origin of the pain has multifactorial pathogenesis, with different factors being able to trigger the same sort of clinical picture.

* **Address correspondence to Stefan Hellinger:** Orthopedic Department, ISAR Klinik, Munich, Germany; E-mail: hellinger@gmx.de

Federico Landriel and Eduardo Vecchi (Eds)

With the aid of appropriate conservative therapy, approximately 80 percent of all cervical syndromes can be cured [1]. Only once all the conservative and semi-invasive procedures have been exhausted surgery should be considered.

In the recent years attempts have been made to preserve the physiological mobility of the diseased movement segment by the use of intervertebral prosthesis (artificial discs). This development will undoubtedly produce interesting results. The other focus of attention was on reducing surgical trauma and access morbidity. The first step was the introduction of the operating microscope by Hankinson and Wilson in 1969 [2]. Other innovations, such as high-speed burrs and bipolar electrocoagulation, produced a further reduction in surgical trauma.

With the aim of miniaturizing the treatment, non-endoscopic percutaneous procedures were soon being used on selected patients, and these also produced good results and a complication rate of less than 1 percent [3]. Thus, chemonucleolysis, which was introduced by Smith in 1964 [4], was performed on the cervical spine. Similarly, automated discectomy [5], percutaneous laser disc decompression and nucleotomy [6] and the use of radiofrequency broadened the percutaneous spectrum.

As a bridge between open and percutaneous therapy, endoscopy of the cervical spine started to be used at the beginning of the 1990s, following good experiences on the lumbar spine [7 - 9]. The principle of microsurgery is combined with the minimally invasive principles by bringing the optical level to the forefront of pathology. Access morbidity has been significantly reduced by the percutaneous access technique. Furthermore, a large proportion of the intervertebral disc, in particular most of the fibrous ring, is preserved. The pathology is only removed selectively in the area of the nucleus pulposus and on the dorsal fibrous ring. This preserves the remaining biomechanical function of the degenerated intervertebral disc. By means of tried and tested minimally invasive methods under vision, such as the use of a laser to ablate and shrink tissue, the risk of complications has been further reduced, at the same time as enhancing efficiency. The advancement of the endoscopic technique with increased miniaturization of the telescope and working options led to a restriction of use (*e.g.* LASER system).

Our objective was to create an adequate working space in front of the telescope while preserving the minimally invasive approach. This was achieved by the use of dilation sheaths, which force the base plate and upper plate apart in the manner of a Caspar retractor and permit a working field of 5 mm or 6 mm. Here, visualization is sufficient to expose the ventral epidural space. A swiveling maneuver of the endoscope enables the dorsal section of the intervertebral disc to be visualized from one uncovertebral joint to the other. Removal of disc material is limited to the pathologic part, in a similar way to arthroscopic meniscus surgery. Equally, the surgeon has to become accustomed to the fact that limited viewing fields are lined up, rather as in joint arthroscopy. An irrigation system is used to rinse the ablated disc material out of the viewing field and to achieve partial hemostasis. Endoscopic cervical discectomy can also be performed using a gas medium. In this case, it is advisable to use a familiar view, such as through a microscope, to facilitate differentiation of the individual structures.

INDICATIONS

- Neck pain radiating into the arm (radicular pain)
- Symptoms of segmental dysesthesia
- Motor deficits matching the pathologic segment
- Conservative therapy-resistant
- Vertebrogenic headache with reliable imaging
- Disc herniation confirmed by MRI or CT, with associated clinical picture
- Damage in adjoining segments after preceding fusion, with corresponding clinical picture
- Multisegment disc herniation

CONTRAINDICATIONS

- Serious cervical spinal stenosis
- Migrated free disc sequestration
- Pronounced spondylosis with large osteophytes
- Calcifications of the posterior spinal ligament

As further instruments for endoscopic intervertebral disc surgery are developed, the scope of application can undoubtedly be extended.

CHAPTER 9

Cervical Arthroplasty

Jose R. Prina[1,*], Ramiro T. Gutierrez[1], Ana F. Cassini[1], Manuel Quinteros, Alberto Yañez[1, 2], Pablo Rubino[3]

[1] *Department of Neurosurgery, Spine Division, Clínica Güemes, Luján, Buenos Aires, Argentina*

[2] *Department of Pediatric Neurosurgery, Hospital Pedro de Elizalde, Buenos Aires, Argentina*

[3] *Department of Neurosurgery, Hospital de Alta Complejidad "El Cruce", Florencio Varela, Buenos Aires, Argentina*

Keywords: Arthroplasty surgical video, Cervical arthroplasty, Cervical spine, ProDisc-C.

GENERAL ASPECTS

The use of an artificial cervical disc is a technique that can replace the classical discectomy and fusion for lesions in the lower cervical spine. The purpose of this design is to reproduce the function of the intervertebral disc.

INDICATIONS

- Patients under 50 years-old with cervical mobility conservation confirmed with dynamic x-rays.
- Preferably 1 affected level.
- Up to 2 levels in specific cases.
- Soft disc herniation.
- Hard disk herniation (even with 1 level osteophytes) with cervical mobility conservation confirmed with dynamic x-rays without facet degeneration.

SURGICAL TECHNIQUE

Under general anesthesia, the patient is placed in supine position with a small shoulder roll and the head in neutral position. The surgical level is marked using

* **Address correspondence to Jose R. Prina:** Department of Neurosurgery, Spine Division, Clínica Güemes, Luján, Buenos Aires, Argentina; E-mail: josericardoprina@hotmail.com

Federico Landriel and Eduardo Vecchi (Eds)

lateral fluoroscopy. Microscope was placed face to face. An approximately 3-5 cm transverse incision is planned. We prefer the left-sided approach because the recurrent nerve follows a more predictable path on this side. The platysma fibers are longitudinally opened approximately 2 cm lateral to the midline. With blunt dissection the medial border of the carotid sheath is separated from the lateral border of the trachea and esophagus. The prevertebral fascia is exposed and the disc space is identified. Intraoperative lateral fluoroscopy confirms the disc space. Subperiosteal detachment of the longus colli muscles is performed from the rostral to the caudal uncovertebral joints.

A radiolucent self-retaining retractor is placed. The midline is marked between the uncovertebral joints; this is a crucial step to ensure a proper device alignment. An annulotomy is performed with a scalpel blade to begin the discectomy. The disc is removed with pituitary rongeurs and curettes. Pilot holes are drilled to introduce the distractors pins. The pins are placed in the previously marked midline, parallel to the endplates and in the center of each vertebral body. A radiolucent Caspar cervical distractor allows the remainder disc remotion. The opening of the posterior longitudinal ligament is always performed to allow a symmetrical distraction of the disc space. The endplates are prepared to device implantation. A probe is used to determine implant size. Lateral intraoperative fluoroscopy control. The device is inserted with strict alignment in the midline. The wound is closed as usual, skin is closed with a subcutaneous running 4.0 monocryl suture.

COMPLICATIONS

- Surgical site infection
- Esophageal injury
- Carotid injury
- Recurrent nerve injury
- Suffocating hematoma
- Durotomy
- Spinal cord injury (myelomalacia) due to incorrect implant placement
- Wrong choice of implant size (over-distraction)
- Incorrect positioning (paramedian)
- Poor surgical technique (incomplete discectomy, excessive endplate curettage,

excessive lateral discectomy).

POSTOPERATIVE MANAGEMENT

The average length of hospitalization is 24 hours. No neck braces of any kind are indicated. Nonsteroidal anti-inflammatory drugs (NSAIDs) are prescribed in the first 48-72 hours if pain. The average time for return to normal activities is 30 days.

OUTCOMES

From the 50s to the present, symptomatic herniated cervical disc were successfully treated with surgical techniques developed by Cloward [1] and Smith and Robinson [2]. Reports of cervical arthroplasty date back to more than thirty years but did not show a proper follow up to allow a reliable assessment of the results. On the other hand, the devices had serious design problems, which ultimately led to the abandonment of these emergent techniques [3].

Subsequently, arthroplasty was refloated with new implant designs [4]. Cummins [5], in 1998, reports the promising results of a series of 20 patients operated using his own design disc replacement device.

In 2003, Wigfield [2, 9] published a case series of 15 patients using a design disc replacement. He reports the preservation of motility in all cases except one, and improvement of pain in 46%.

The use of cervical disc is a relatively new technique that is presented as an alternative to the classic discectomy and fusion surgery used for degenerative lesions of the sub-axial cervical spine. The development of this technique arises from the need to find a design that can reproduce, in a physiological way, the function of the intervertebral disc [6 - 8].

For young patients with 3-month history or more of cervical radicular pain due to a herniated disc, cervical arthroplasty, for its benefits, is presented as an excellent treatment option [6].

Biomechanical studies have shown that the fusion or arthrodesis of a spinal level

CHAPTER 10

Anterior Cervical Corpectomy

Augusto Gonzalvo*, **Bryden Dawes**

Department of Neurosurgery, Austin Health, University of Melbourne, Australia

Keywords: Anterior cervical corpectomy video, Corpectomy surgical technique, HD Surgical video corpectomy.

GENERAL ASPECTS

The anterior cervical corpectomy has been used for the treatment of several pathologies including degenerative disease, trauma and tumors.

The purpose of the intervention is to decompress the spinal cord and nerve roots, re-establishing cervical lordosis, stabilizing the spine and achieving fusion.

This technique can address one or more vertebral bodies or it can be used in combination with discectomies above or below the corpectomy level (hybrid constructs).

The anterior cervical corpectomy is the best option to address a ventral compression in the sub-axial cervical spine. However, in some patients it may present significant limitation in the access to the top and bottom vertebrae (C3 and C7).

INDICATIONS AND CONTRAINDICATIONS

The anterior approach to the subaxial cervical spine utilizes an avascular corridor between the pretracheal fascia, infrahyoid muscles and esophagus medially and sternocleidomastoid and the carotid sheath laterally. The versatile approach allows access to the anterior vertebral body and may be used when undertaking a cervical corpectomy, decompression and fusion, cervical disc arthroplasty or

* **Address correspondence to Augusto Gonzalvo:** Department of Neurosurgery, Austin Health, University of Melbourne, Australia; E-mail: augusto.gonzalvo@gmail.com

Federico Landriel and Eduardo Vecchi (Eds)

instrumentation. Whilst there are no absolute contraindications for the approach, special consideration should be given to patients with previous neck surgery or radiotherapy, concurrent tracheostomy and ossification of the posterior longitudinal ligament.

In the presence of recurrent laryngeal nerve palsy, an approach through the contralateral side to the palsy is contraindicated due to the risk of bilateral recurrent laryngeal nerve palsy.

SURGICAL TECHNIQUE

Patient Positioning

Following general anesthesia and endotracheal intubation, the patient is placed supine on the operating room table with the head in the neutral position. Maintenance of cervical lordosis is achieved *via* placement of a gel mat or roll under the shoulders and the occiput placed on a donut shaped gel mat or horseshoe ring, with the arms adducted and fixed with appropriate padding to prevent compression injuries. Whilst extension of the cervical spine aids visualization, hyperextension in patients with significant cervical canal stenosis or an unstable spine should be avoided as it may worsen neurological deficits. Some surgeons position the head rotated away from the side of the incision.

Caudal traction of the shoulders with tape may be useful to facilitate accurate intraoperative radiographs when approaching the lower cervical spine or in patients with a large body habitus, however excessive traction may lead to injury of the brachial plexus. Whilst not routinely used by the authors, intraoperative evoked potentials, motor or somatosensory, may be used to avoid inadvertent neural injury.

This monitoring has been found not to be specific for neural injury and positive findings neither identifying neural damage nor predicting poor clinical outcome [1, 2]. Following positioning, the neck and upper chest are prepped and draped, as well as the iliac crest if bone graft is required.

Approach

Both transverse and longitudinal incisions may be used for the anterior approach to the cervical spine. However, for single or two level operations, a unilateral transverse incision in a skin fold or Langer's line is used and is made from midline to the anterior border of sternocleidomastoid. Preoperative radiographs can be used to localize the appropriate level, however the authors use MRI and anatomical landmarks such as the thyroid cartilage for incision planning. Typically a right-sided incision for a right-handed surgeon is used however a left-sided approach may be useful when accessing primarily right-sided lateral pathology.

There is no difference in the incidence of symptomatic recurrent laryngeal nerve injury with either approach [3, 4]; however, the incidence of asymptomatic nerve injury may be slightly higher when approaching from the right [5] and the thoracic duct is at risk when accessing from the left. For access to greater than two cervical levels, either a longitudinal incision along the anterior border of sternocleidomastoid or a bilateral transverse incision is used.

Following a skin incision, platysma is opened with monopolar diathermy transversely to the longitudinal fibers. Platysma is then mobilized cranially and caudally with sharp dissection in the subplatysmal layer. Care must be taken when encountering branches of the external jugular vein, which may be retracted, ligated or coagulated with bipolar diathermy and divided.

The investing fascia is then divided along the medial border of sternocleidomastoid. A combination of blunt and sharp dissection is then used to identify the avascular plane between sternocleidomastoid and the infrahyoid muscles. It is vital that the carotid sheath remains lateral during the dissection. Omohyoid may be encountered during the approach as it traverses the anterior triangle of the neck at the C5/6 level and may be retracted cranially, caudally or divided to allow accurate visualization.

Once the prevertebral fascia is identified, it is exposed with blunt dissection with peanut swabs. The fascia is opened in the midline with sharp dissection, with longus colli used as a midline anatomical landmark. A level check with a lateral

CHAPTER 11

Minimally Invasive Posterior Cervical Foraminotomy

Jorge Mendoza Torres, Mick Perez-Cruet*

Michigan Head and Spine Institute, USA

Keywords: Cervical foraminotomy video, Foraminotomy, Laminectomy, Minimally invasive.

INDICATIONS

The indication for a minimally invasive posterior cervical foraminotomy (MI-PCF) starts when a patient comes to the office complaining of acute cervical radiculopathy and an intraforaminal and posterolateral soft disc herniation or foraminal stenosis (Fig. **1**) are noticed in the imagenology [1].

1. Foraminal Stenosis
   - -Foraminal osteophyte
   - -Local thickening of ligamentous flavum
2. Lateral Disc Herniation

Neural foramina stenosis of the cervical spine is a degenerative disease and compresses the nerve roots as they leave the spinal canal. Foraminal stenosis can be attributable to an acute process like a disc herniation or a chronic process like degeneration in the disc or facet joints.

The advantage of MI-PCF is the avoidance of fusion and early return to functional life. The disadvantages are difficulty in eliminating osteophytes ventral to the nerve root, and if more than 50% of the facet is removed there is risk of potential cervical instability [2, 3].

* **Address correspondence to Mick Perez-Cruet:** Michigan Head and Spine Institute, USA; E-mail: perezcruet@yahoo.com

Federico Landriel and Eduardo Vecchi (Eds)

Fig. (1). Showing right-sided cervical foraminal stenosis (arrow) by a C5-6 posterolateral herniated disc.

CONTRAINDICATIONS

If the patient complains about posterior neck pain without neurological symptoms or a gross cervical instability, symptomatic central disc herniation, kyphotic deformity and diffuse ossification of posterior longitudinal ligament are ruled; then, there will be a potential contraindication for MI-PCF [4].

SURGICAL TECHNIQUE

The patient is brought to the operating room and general endotracheal anesthesia is administered. Somatosensory-evoked potentials and motor-evoked potentials leads are placed and the baseline signals are logged. The bed is then bent at the waist level to elevate the patient into a seated position with the knees slightly flexed. The patient is then placed in pins in the Mayfield head-holder and then secured to its attachment (Fig. **3**).

- A C-arm is then brought into the field and positioned to take a lateral x-ray with the arc positioned towards the floor.
- After the patient has been prepared and draped in a sterile fashion, the correct level of surgery is localized.
- A 2-cm stab incision is made ipsilateral at the level of pathological lesion approximately 1-cm off midline. The skin, subcutaneous tissue, and fascia are opened in layers. Blunt dissection is performed with Metzenbaum scissors to safely delineate the cervical lateral mass before dilation.
- A series of dilators are then passed to separate the soft tissue in the neck followed by an 18-mm tubular retractor. The dilators are removed and the retractor is locked in position at the junction of the lamina and lateral mass (Figs. **2** and **5**).

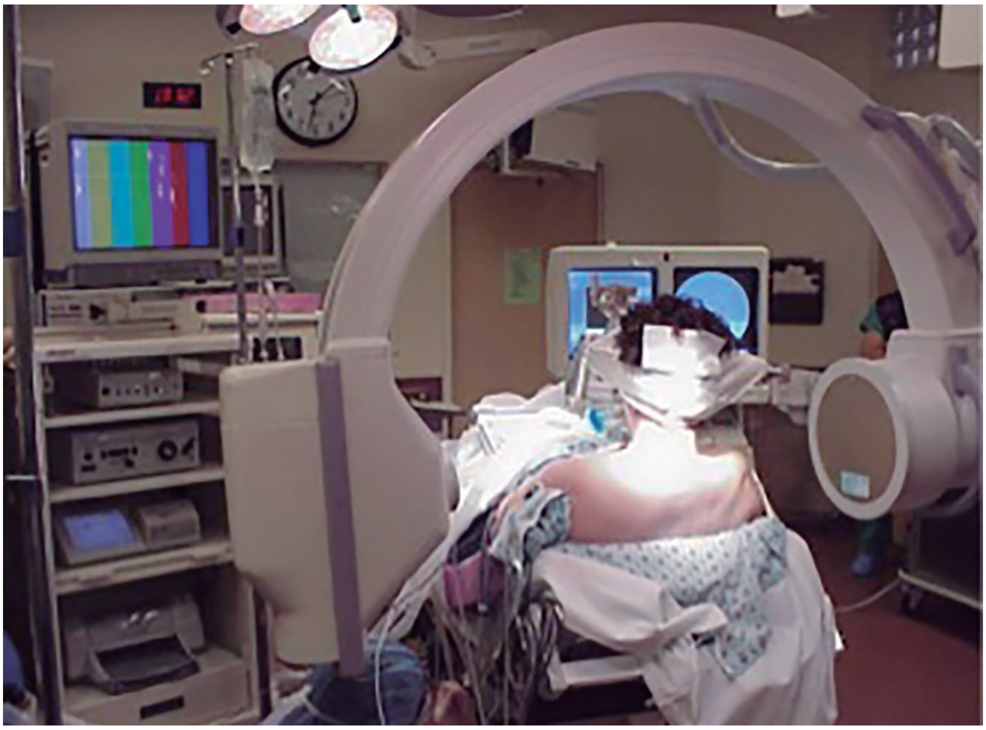

Fig. (2). Showing the right place for docking the tubular retractor.

- The endoscope is introduced into the working channel and locked in place (Fig. **4**). Lately, we are no longer using endoscope; instead, we are using microscope

CHAPTER 12

Open Posterior Cervical Foraminotomy (Keyhole Approach)

Federico Landriel*, Eduardo Vecchi, Santiago Hem, Nicolas Tedesco

Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina

Keywords: Key-hole surgical technique, Key-hole HD video, Microlaminotomy-foraminotomy video, Posterior cervical foraminotomy video.

GENERAL ASPECTS

The first posterior cervical approaches to treat disc herniation were wide bilateral decompressive laminectomies. Subsequently, the surgical procedure evolved to a microlaminotomy-foraminotomy (keyhole) by limiting the soft tissue and bony opening, thus improving safety around sensitive neurostructures and avoiding potential postoperative deformity. Lately, blunt muscle-splitting (function-preserving) approaches were developed using minimally invasive tubular retractors. Although its indication is more limited than anterior approaches, the posterior cervical foraminotomy avoids the retraction on the esophagus and potential laryngeal nerve injury, pseudarthrosis and graft subsidence, which are well-reported complications of anterior cervical discectomies [1].

INDICATIONS

- Radiculopathy due to lateral or foraminal soft disc herniation or spondylotic spurs

CONTRAINDICATIONS (RELATIVE *)

- Myelopathy
- Central disc herniation
- Alignment abnormalities

* **Address correspondence to Federico Landriel:** Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina; E-mail: fedelandriel@gmail.com

Federico Landriel and Eduardo Vecchi (Eds)

- Posterior longitudinal ligament ossification
- * Bilateral or multiple level compression
- * Chronic axial mechanical neck pain

SURGICAL TECHNIQUE

Under general anesthesia, somatosensory-evoked potentials and motor-evoked potentials baseline signals are monitored. A Doppler ultrasound is used for continuous venous air embolism monitoring. The patient is placed in a sitting position with the knees slightly flexed and the head fixed with a Mayfield head-holder. Slight cervical flexion improves visualization of the interlaminar spaces. Lateral fluoroscopy is used to confirm the surgical level. The patient is draped in a sterile fashion.

A 3-4 cm midline skin incision is made for a single level disc exposure. A unilateral subperiosteal approach exposed the right side of the spinous process, laminae and the facet joint. A self-retaining retractor is applied. The level is re-confirmed with a needle and lateral fluoroscopy.

The interlaminar space is identified and cleared of overlying soft tissue with monopolar cautery. Using the high-speed drill, the lamino-foraminotomy is performed beginning with a cutting bit toothed ball tip burr. The posterolateral part of the cranial lamina and the medial portion of the inferior articular facet are drilled first. The medial one-third of the facet is progressively removed (up to 5 mm) [2]. A diamond tip burr is used to drill the medial portion of the superior facet and lateral part of the caudal lamina (inner part of the pedicle), leaving a thin shell of bone against the nerve. An approximately 1.5 cm round opening is completed using Kerrison rongeurs (Fig. **1**). The ligamentum flavum is identified and incised, thus exposing the lateral part of the dura. A layer of fibrous tissue containing epidural veins lies immediately beneath the thin lateral part of the ligamentum flavum; this can be dissected or divided using bipolar cautery. The nerve root is located above the pedicle and immediately under the cranial facet. Lateral soft disc herniations are usually encountered beneath the axilla of the nerve root (Fig. **2**). Using a ball tip nerve hook the disc space is exposed. The annulus and posterior longitudinal ligament are opened if necessary with a No. 15 blade. The extruded disc fragments are removed with a small pituitary rongeur, suction, or a small nerve hook. Decompression of the nerve root is confirmed using a nerve hook.

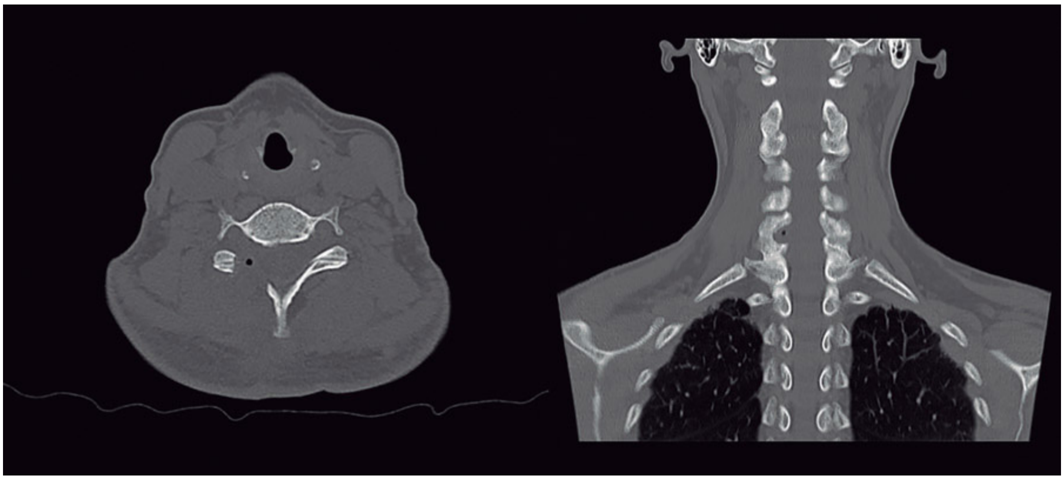

Fig. (1). Postoperative axial and coronal CT demonstrates keyhole right foraminotomy with less than 50% of lateral mass for facet remotion.

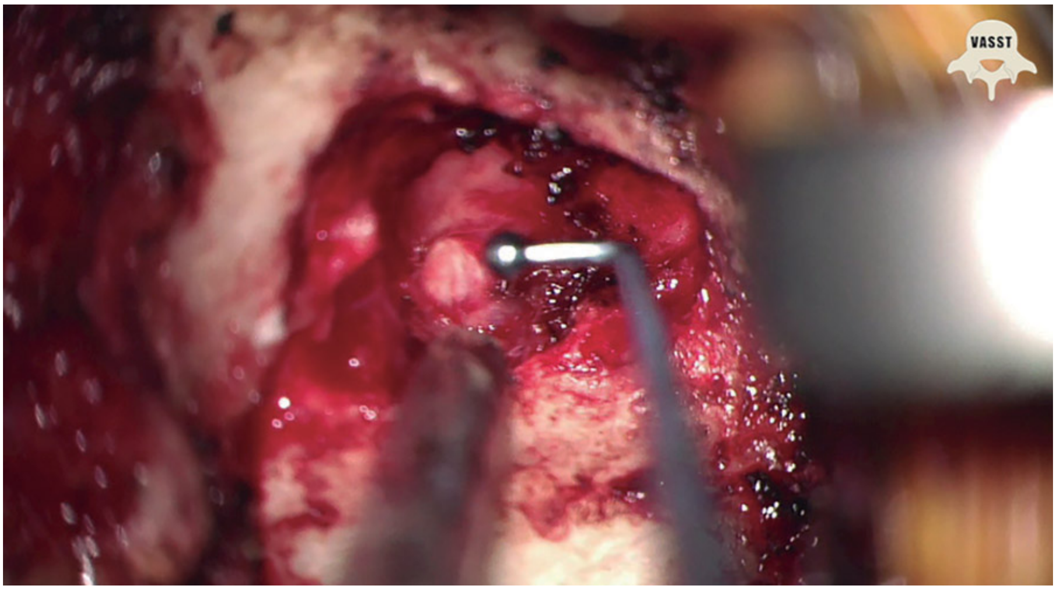

Fig. (2). Shows intraoperative soft disc herniation between the dura and nerve root axilla.

Hemostasis is archived. It is not advisable to enter the disc space from this

CHAPTER 13

Bilateral Decompression through Unilateral Approach for Cervical Stenosis (Tubular Approach)

Albert P. Wong*, Najib E. Tecle, Nader S. Dahdaleh, Richard G. Fessler

Department of Neurosurgery, Rush University Medical Center, Chicago, Illinois, USA

Keywords: Cervical stenosis video, Endoscopic, Laminectomy, Minimally invasive.

CASE PRESENTATION

A 79 year-old right handed male with a five-year history of radiating left lower extremity pain and weakness. He also describes difficulties with fine motor movements of the hands with mild weakness. He describes some gait difficulties and imbalance for the past year. He denies any difficulty controlling his bladder or bowel function. He has tried medical management without improvement in his symptoms. On physical exam, the patient demonstrates mild weakness in his bilateral biceps, triceps and hand function. He also has some mild weakness in his tibialis anterior and extensor hallucis longus. His reflexes are mute in all four extremities. There is no clonus, Babinski sign or Hoffman's sign on examination.

IMAGING STUDIES

An MRI of the cervical spine without contrast demonstrates degenerative disc disease with spinal cord compression most severe at C4-5 and C5-6 from a combination of disc herniation, hypertrophic facets and buckling of the ligamentum flavum. There is no evidence of edema in the spinal cord on imaging (Fig. **1**).

* **Address correspondence to Albert P. Wong:** Department of Neurosurgery, Rush University Medical Center, Chicago, Illinois, USA ; E-mail: wong@fsm.northwestern.edu

Federico Landriel and Eduardo Vecchi (Eds)

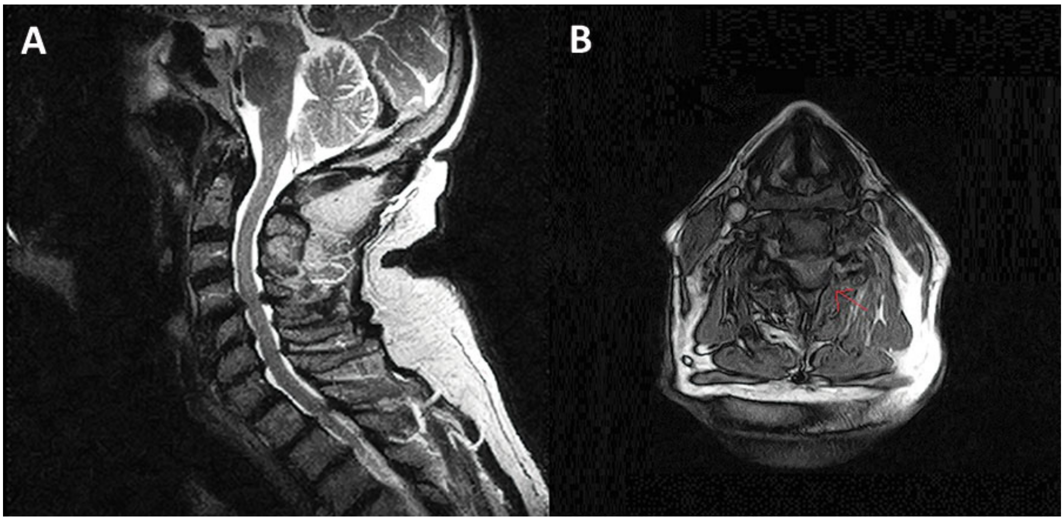

Fig. (1). A. T2 sagittal MRI and **B.** T2 axial MRI (right) of the cervical spine demonstrates moderate to severe spinal cord compression at C4-5 and C5-6. The red arrow points at the compressed spinal cord. There is no evidence of spinal cord edema.

SURGICAL TECHNIQUE

Positioning

The patient is intubated under general anesthesia and placed in the "sitting position" to decrease pooling of blood in the surgical field and improve visualization. A Mayfield three-point pin fixation head holder is used to secure the head to the operating table. The neck is gently flexed to improve the intraoperative surgical exposure. All bony prominences and vulnerable pressure points are padded. The skin is shaved and cleaned with alcohol. The midline is marked with a skin marker over the prominent spinous processes and a parallel skin incision is drawn 1.5cm ipsilateral (left) of the midline (Fig. **2**). Once the skin incision is localized over C4-C6, sterile surgery drapes are placed in wide fashion around the operative field. The skin is scrubbed with betadine solution for five minutes, then "painted" with alcohol and allowed to dry spontaneously. The skin incision site is remarked with a sterile skin marker after the alcohol has dried completely. The surgical area is finally prepped with an iodine and alcohol solution (DuraPrep™, 3M™). Sterile towels are used to border the sterile surgical field followed by a sterile antimicrobial impregnated sterile film (Ioban™, 3M™).

The remaining surgical field is isolated with sterile drapes in standard fashion. Confirmation of the C4-C6 disc spaces are localized by counting vertebral bodies with fluoroscopy in the lateral position from the occiput down to C4-C6.

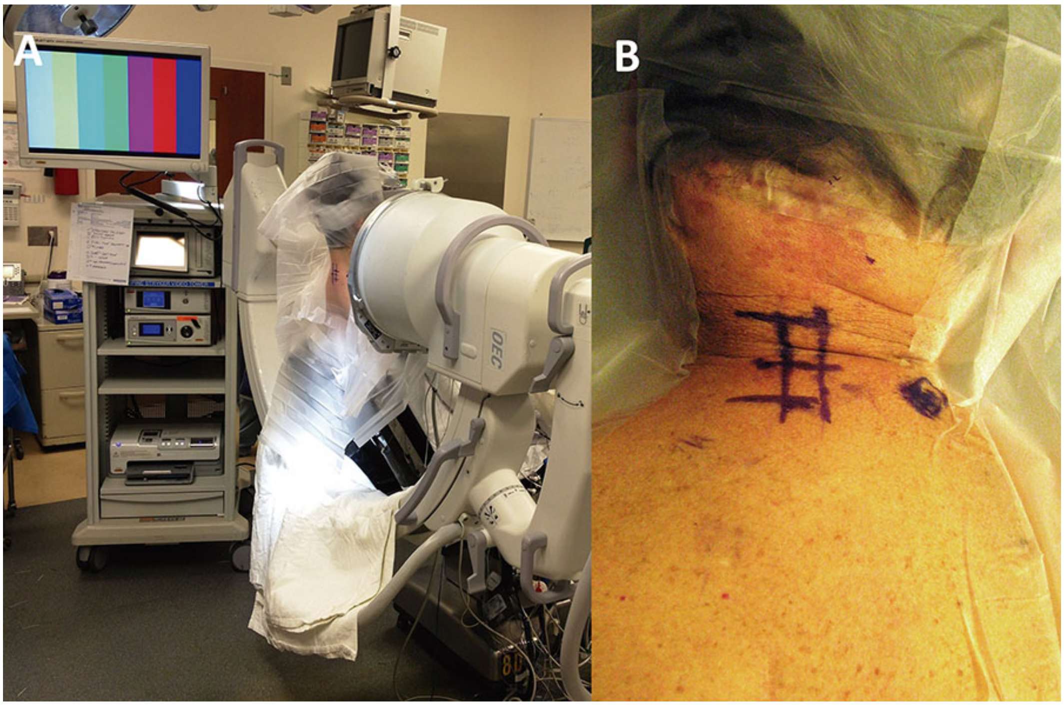

Fig. (2). A. The patient is placed in the " sitting position" and the fluoroscope is positioned for lateral X-rays. **B.** Magnified view of the incision drawn fifteen millimeters lateral to the midline.

Intraoperative Neurophysiologic Monitoring

Somatosensory evoked potentials and motor evoked potentials are placed during general anesthesia prior to final positioning of the patient.

Incision

The original skin incision was marked and localized with fluoroscopy fifteen millimeters ipsilateral to the midline. The incision is infiltrated with a combination of 0.5% Marcaine and 1:200,000 Epinephrine solution for local anesthesia and hemostasis. The incision length is made with a #15 scalpel blade about thirty millimeters long.

CHAPTER 14

Open Cervical Reduction Techniques

George M. Ghobrial*[, 1], Mark E. Oppenlander[1,3], Alan S. Hilibrand[2], Srinivas K. Prasad[1], James S. Harrop[1,3]

[1] *Department of Neurological Surgery, Thomas Jefferson University Hospital, Philadelphia, PA, USA*

[2] *Department of Orthopedic Surgery, The Rothman Institute, Thomas Jefferson University Hospital, Philadelphia, PA, USA*

[3] *Division of Neurological Surgery, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, Arizona, PA, USA*

Keywords: Metastatic epidural spinal cord compression, Open cervical reduction video, Spinal tumor.

GENERAL ASPECTS

Cervical facet dislocations are not infrequent, with one single institution clinical series encountering approximately 80 cases in 12 years [1]. These fractures commonly occur due to a traumatic mechanism, often occurring at high translational forces as in motor vehicle accidents. Vertebral subluxation greater than 50% is the result of bilateral facet dislocation, where unilateral dislocations have subluxation around 25%. Completely dislocated facets are said to be 'locked' or 'jumped', when the inferior facet is disarticulated and translated dorsal to the adjacent superior facet.

A facet is said to be 'perched' when the facets are partially dislocated, with the tips of each facet touching without making even contact in a high-energy state where reduction or dislocation is possible.

This alignment of facet dislocation is achieved under a flexion-distraction mechanism.

* **Address correspondence to George M. Ghobrial:** Department of Neurological Surgery, Thomas Jefferson University Hospital, Philadelphia, PA, USA; E-mail: georgeghobrial@gmail.com

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INDICATIONS AND CONTRAINDICATIONS

- Failure to achieve facet reduction in awake patients under closed conditions with Gardner-Wells tongs remains the most common indication for open reduction and stabilization
- In the case of 50% subluxation or greater, there is often severe ligamentous disruption and thus an unstable spine. Even after a closed reduction is performed a surgical stabilization should be considered to maximize neurologic protection.
- In the setting of facet dislocation, particularly with neurologic impairment, a reduction provides immediate spinal cord decompression and biomechanical stabilization. This may provide the patient with spinal cord injury an improved chance of recovery.
- Additional indications for the open reduction of cervical spine fractures include the need for careful reduction in the setting of multiple fractures, acute herniated discs, preexisting spinal disease such as ankylosing spondylitis, or essentially any high-risk condition that may lead to a worsening neurologic exam.

Cervical dislocations can be reduced from either an anterior or posterior approach.

- The posterior approach is often preferred, given the ability to comprehensively provide decompression, an exposure of the facets, a direct reduction, and definitive stabilization with spinal instrumentation. A posterior approach tends to be technically less challenging. The posterior approach can be performed with or without an anterior approach.
- One relative contraindication to the posterior reduction is a large ventral compressive force with the concern for exacerbating the compression by a posterior reduction.
- The addition of an anterior approach is indicated in the presence of anterior pathologies such as ventral compression from a herniated disc, fracture fragment, or epidural hematoma, or if additional biomechanical stabilization is deemed appropriate.
- The anterior approach may be used as the primary open reduction technique in selected cases of cervical locked facets. Success of this technique requires intraoperative force applied to the endplates of the rostral and caudal vertebral bodies in order to effect reduction.

- Pitfalls of the anterior approach for reduction include the possible inability to reduce the dislocation, in which case a posterior approach is taken, and the theoretical need to augment the fusion posteriorly.

SURGICAL TECHNIQUE FOR POSTERIOR OPEN CERVICAL REDUCTION

The patient is placed prone, under general anesthesia, with neurophysiologic monitoring of somatosensory evoked potentials, motor evoked potentials, and electromyography. Surgical reduction should not be delayed for neuromonitoring. Landmarks for the prominence of C7, spinous process prominence of C2, and occiput allow for estimation of incision without the use of intraoperative imaging.

A posterior midline incision is made and the dissection is carried out along the spinous processes, laminae, and lateral masses in a subperiosteal fashion. Exposure extends laterally to the lateral edges of the lateral masses. Care is taken not to destabilize levels adjacent to the anticipated fusion construct by avoiding cauterization of adjacent facet joints. Care must be taken with the dissection since there are often fractures along the laminae and the spinal cord can be exposed.

In the case of locked facets, the inferior edge of the inferior facet of the superior vertebra will be ventral to the adjacent superior facet below. Often, in the absence of laminae and spinous process fractures, traction can be placed on the spinous process with Kocher clamps or sharp towel clips, and the segments can be reduced carefully in this manner.

However, in the presence of fractures, there may be concerns for worsening destruction with this technique. The surgeon may also be unable to achieve reduction in this manner. In these cases, the superior edge of the superior facet of the inferior vertebra can be drilled away in order to aid reduction.

Intraoperative traction is another tool for facilitating open reduction. Care must be taken, however, not to over apply weight in the settings of three-column ligamentous disruption or additional cervical fractures. The presence of occipitoatlantoaxial injury is a relative contraindication to traction.

Given the inherent instability of locked facets, stabilization of the affected levels

CHAPTER 15

Open Posterior C1-C2 Arthrodesis

Paul Klimo, Jr.[1,2,3,*], Nelson Astur Neto[4], William C. Warner, Jr.[4], Michael S. Muhlbauer[1,2,3]

[1] *Semmes-Murphey Neurologic & Spine Institute, Memphis, TN, USA*

[2] *University of Tennessee, Department of Neurosurgery, Memphis, TN, USA*

[3] *Le Bonheur Children's Hospital, Memphis, TN, USA*

[4] *Campbell Clinic Orthopaedics, Memphis, TN, USA*

Keywords: C1-2 arthrodesis, Harms construct video, Os dontoideum, Screw fixation.

GENERAL ASPECTS

Os odontoideum is an anatomical abnormality in which the tip of the odontoid process lacks continuity with the body of C2 (Fig. **1**). It appears as a smooth-margined, apical osseous segment separated from the base of the odontoid process by a wide transverse gap. It was once believed that os odontoideum was purely a congenital lesion caused by a failure of fusion between the first and second sclerotomes (*i.e.*, across the neurocentral synchondrosis). Today, it is thought that many cases of os odontoideum cases are the result of remote trauma to the odontoid with subsequent avascular necrosis of the midportion of the odontoid and retraction, and thus separation of the tip; however, faulty embryogenesis may be the cause in some cases, such as the one presented here [1].

Patients with os odontoideum can have local symptoms, such as neck pain or occipital headaches; they can develop sudden onset quadriparesis or plegia, classically after a minor traumatic event; or they can have progressive myelopathy due to repeated microtrauma to the spinal cord [2]. The spinal cord is at risk for injury in patients with os odontoideum because of excessive motion of the ring

* **Address correspondence to Paul Klimo Jr.:** Semmes-Murphey Neurologic & Spine Institute, Memphis, TN, USA; E-mail: pklimo@semmes-murphey.com

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and os odontoideum complex. This instability may be categorized as anterior, posterior, or both (Fig. **2**).

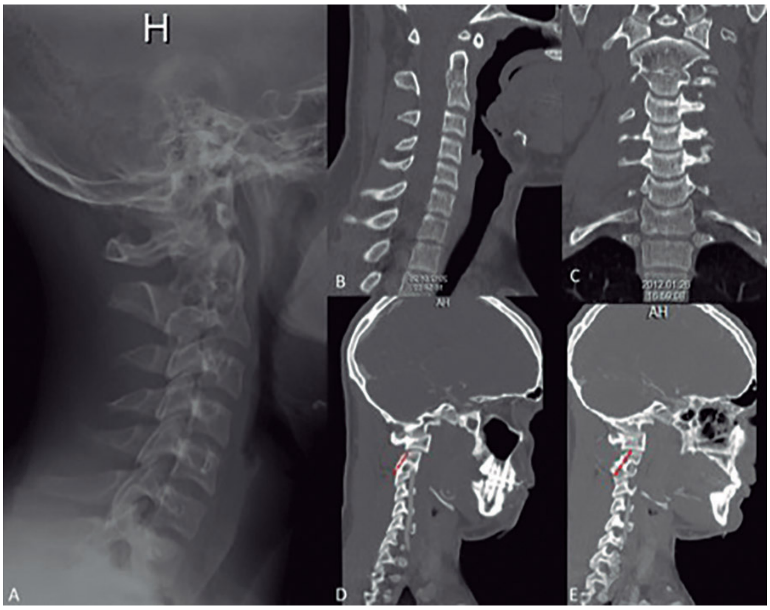

Fig. (1). Preoperative imaging studies; os odontoideum + C2-3 congenital fusion + C1-2 instability. A: lateral radiograph; B: sagittal CT; C: coronal CT; D: parasagittal CT with C2 right side pars screw path highlighted for the right side; E: parasagittal CT with C2 left side pars screw highlighted.

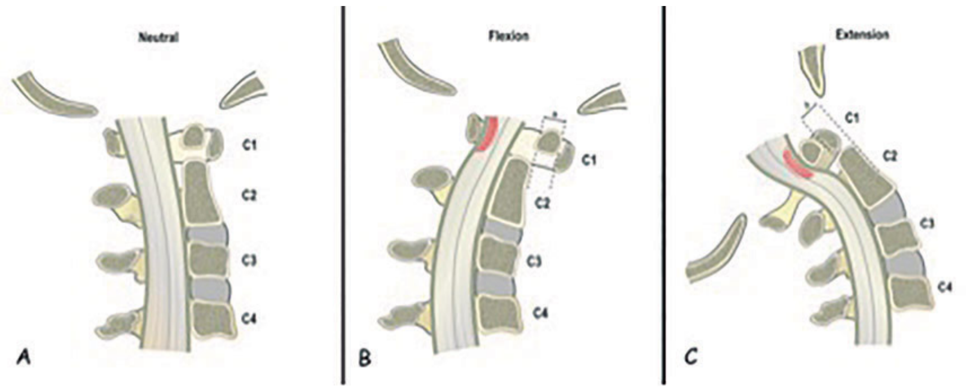

Fig. (2). With an os odontoideum (A), abnormal motion may occur anteriorly, posteriorly, or both. Flexion (B) can cause translation of the C1 ring and ossicle complex to the point that it may impinge upon the dorsal aspect of the cord. On extension (C), the anterior ring with the ossicle can strike the ventral aspect of the cord. *Reprinted with permission from Klimo et al.: Os odontoideum: presentation, diagnosis, and treatment in a series of 78 patients. J Neurosurg Spine 9, pp 333, 2008.*

In this chapter, we will address the surgical management of a patient with os odontoideum and congenital C2-3 fusion (*i.e.* failure of segmentation) with excessive motion (8 mm) between the C1 and the C2-3 complex (see video).

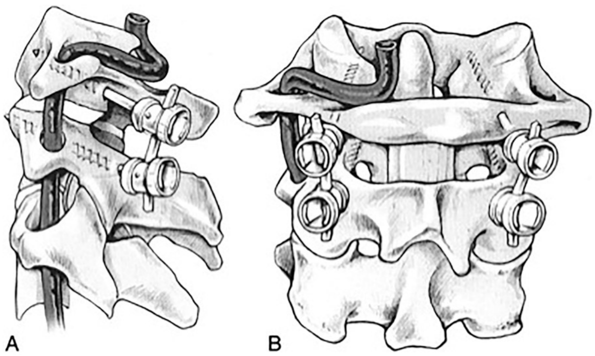

Fig. (3). The Harms construct: C1 lateral mass screws and C2 pedicle screws connected with a rod for C1-2 fusion. Lateral (A) and posterior (B) views with the position of the vertebral artery are shown. *Reprinted with permission from Harms J, Melcher RP: Posterior C1-C2 fixation with polyaxial screws and rod fixation. Spine 26, pp 2469, 2001.*

The surgical procedure is a C1-2/3 fusion with lateral mass screws at C1 and pars interarticularis screws for C2/3 connected with a rod – the so-called "Harms construct" - and posterior iliac crest autograft. Although the original paper by Jurgen Harms in 2001 described the use of polyaxial C1 lateral mass screws coupled with C2 pedicle screws Fig. (**3**), the term "Harms construct" has since then been used to describe a construct that consists of either C2 pedicle or pars interarticularis screws connected *via* rods to C1 lateral mass screws [3].

INDICATIONS AND CONTRAINDICATIONS

There is clear consensus that patients who present with excessive atlantoaxial motion (>4 mm), a history of sudden or chronic progressive myelopathy, or evidence of prior spinal cord injury on MRI require fusion and fixation. However, controversy surrounds the management of os odontoideum in patients who present with it incidentally or with local symptoms only. Some authors advocate surgery for virtually all patients to prevent potential future catastrophic spinal cord injury regardless of symptoms or amount of motion [4]. This is based on the belief that without an intact odontoid, the remaining supporting structures may not be strong

CHAPTER 16

Laminectomy - Lateral Mass Screw Fixation

Federico Landriel*, Eduardo Vecchi, Santiago Hem, Lucas Garategui, Claudio Yampolsky

Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina

Keywords: Cervical laminectomy, Laminectomy surgical video, Lateral mass screw fixation video, Laminectomy surgical technique.

GENERAL ASPECTS

Posterior surgical decompression is an effective treatment for patients with multilevel cervical spondylotic myelopathy and moderate to severe or progressive neurologic deficits. Standard laminectomy has been considered to be directly associated with an increased risk of postoperative deformity. To avoid this, several methods of subaxial cervical spine stabilization using wires, rods, screws and plates have been described. Lateral mass screw fixation is a safe and effective spinal stabilization/fusion technique [1, 2].

INDICATIONS

- Presence of signs and symptoms of cervical myelopathy secondary to spinal multilevel cord compression (Fig. **1**) as a result of different pathologies (osteophytes, ossification of the posterior longitudinal ligament, flavum ligament infolding or ossification, etc.)
- Focal instability.
- Tumors or connective tissue disease requiring large posterior cervical approach.
- Degenerative or iatrogenic kyphosis.
- Laminectomy is contraindicated as the only procedure in the case of spine rectification or kyphotic deformity. However, its development does not seem to reduce the clinical cervical decompression outcome [1].

* **Correspondence to Federico Landriel:** Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina; E-mail: fedelandriel@gmail.com

Federico Landriel and Eduardo Vecchi (Eds)

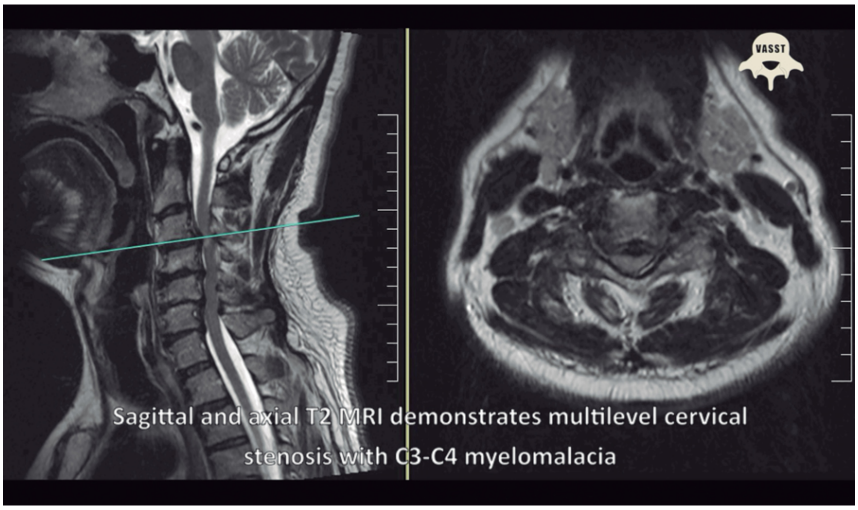

Fig. (1). Preoperative MRI demonstrates spondylotic cervical myelopathy.

SURGICAL TECHNIQUE

Nasal fiber-optic intubation for general anesthesia should be considered to prevent hyperextension injury. Somatosensory-evoked potentials (SSEPs) and motor-evoked potentials (MEPs) baseline signals are monitored. The patient is placed in prone position with rolls under the chest and iliac crests. The head is fixed with a 3-point head holder. Lateral fluoroscopy is used to confirm the surgical level, caudal shoulder traction with adhesive tape may be helpful to improve cervico-thoracic spine lateral x-ray visualization.

A medial incision is planned, usually from the spinous process of C2 to C7. Staying in the midline during fascial dissection, since it is an avascular plane, allows better access to the muscle fascia and cervical spinous processes. Soft tissue dissection with monopolar cautery exposes the spinous processes, laminae and facet joints from C3 to C6. Efforts should be made to preserve muscle attachments to C2 and C7 spinous process, thus decreasing postoperative neck pain. Facet capsule of the most cranial and caudal aspects must be preserved.

The entry site for the lateral mass screw is 1 mm medial and cephalad to its midpoint. Pilot holes are performed with a small cutting bit toothed ball tip burr. Screws trajectory are prepared using a manual drill with a controlled depth of insertion. The tract is palpated with a ball tipped probe to ensure that there is no violation of its walls and bottom. We place the lateral mass screws using Magerl´s technique, 25° laterally in the axial plane and parallel to the facet joint in the sagittal plane.

Two longitudinal troughs are made, medial to the middle portion of the lateral masses, preferably drilling with a match head tip burr, until the yellow ligament is exposed. When manual instruments are used, care should be taken not to further compress the spinal cord. The dura is gently detached from the overlying ligament flavum. A towel clamp is placed on the most caudal spinous process and the laminae with their ligament flavum are gently lifted en bloc. The neuroforamens can be widened and decompressed as necessary with a Kerrison rongeur. The bone is preserved for use as local autograft.

Malleable rods are cut, contoured and placed onto the screw construct. The locking mechanisms are engaged securing the screw and rod construct. Final locking is performed with anti-torque forces, allowing the alignment of screw heads.

The facet joints are decorticated to improve graft interface (Fig. **2**). The autograft is impacted across the lateral aspect of the construct in the interfacetary notch (Fig. **3**).

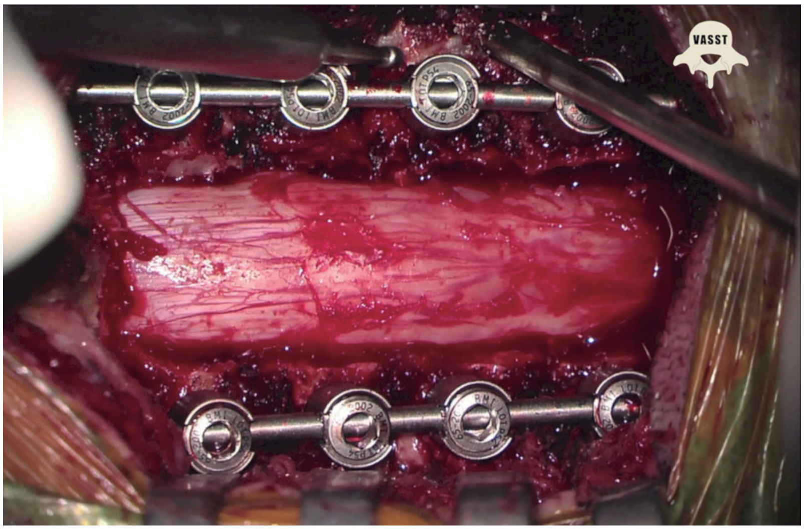

Fig. (2). Intraoperative photograph shows the facet joints are decorticated with a high-speed drill.

CHAPTER 17

Cervical Open Door Laminoplasty

Federico Landriel[1,*], Eduardo Vecchi[1], Michael Cruz Bravo[1], Esteban Calcagni[2,3], Horacio Sarramea[3], Cristian Miltos[4]

[1] *Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina*

[2] *Orthopedic Department, Centro Médico Rivera, BS, AR*

[3] *Orthopedic Department, Centro De Estudio De Las Enfermedades De La Columna Vertebral (CEECV), BS, AR*

[4] *Department of Neurosurgery, Hospital Central del Instituto de Previsión Social, Asunción, Paraguay*

Keywords: Laminoplasty video, Laminoplasty HD surgical video, Open door surgery, Open door technique.

GENERAL ASPECTS

In 1978 Hirabayashi *et al*. [1] introduced a unilateral open door laminoplasty. The benefits of this procedure were to allow simultaneous decompression for multiple segments, and to preserve the posterior muscle structures that would prevent post laminectomy kyphosis and segmental instability.

The aims of cervical laminoplasty are to expand the spinal canal, to secure the spinal stability, to preserve the protective function of the spine, and to maintain physiological mobility of the cervical spine.

INDICATIONS

The best indication of cervical laminoplasty is cervical myelopathy due to spinal canal multilevel stenosis (AP spinal canal diameter < 13 mm) secondary to one or any combination of the following:

* **Correspondence to Federico Landriel:** Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina; E-mail: fedelandriel@gmail.com

- Congenital canal stenosis
- Ossification of the posterior longitudinal ligament (OPLL) in neutral or lordotic cervical sagittal alignment
- Multilevel disc herniations
- Cervical spondylotic changes at more than three segments
- Tumors or connective tissue disease requiring large posterior cervical approach

CONTRAINDICATIONS

- Cervical spine instability
- Severe cervical kyphosis

SURGICAL TECHNIQUE

In case of severe stenosis, fiberoptic intubation should be considered to minimize the risk of hyperextension spinal cord injury. Somatosensory-evoked potentials (SSEPs) and motor-evoked potentials (MEPs) baseline signals are monitored. The patient is placed in prone position with rolls under the chest and iliac crests to avoid abdominal compression (with secondary elevation of venous pressure of the epidural venous plexus), thus reducing operative blood loss. The head is fixed with a three-point pin head holder. The neck should be slightly flexed; extreme flexion must be avoided as it may produce spinal cord ischemia. The table is tilted cranially upward about 15° degrees.

A medial incision is planned from the spinous process of C2 to C7 in a 4 level laminoplasty. The skin is infiltrated with 0.25% bupivacaine with epinephrine to reduce bleeding. Subperiosteal detachment of the paraspinal muscles from the spinous processes and laminae is performed. Lateral masses from C6 to C3 are recognized and exposed until the lateral portions of the facet joint capsules are identified. Using a high-speed air drill, a trough is drilled at the hinge side with a match head cutting burr. Irrigation continued with physiologic saline solution to avoid excessive heat and potential neurologic injury. Care had to be taken to only drill the outer lamina cortex and cancellous bone on this side, leaving the inner cortex intact. The ligamentum flavum between C6 and C7 must be cut until the dura is visualized. We used a 2 mm Kerrison punch to create a small lamina bit to facilitate the creation of the second trough. The same process is repeated between

C2 and C3 levels. This would aid in opening the door. A second trough is drilled down to the ligamentum flavum in the open-door side. The remnant associated ligament is then removed. The laminae on the open side gutter are gently lifted in greenstick fashion with a Penfield dissector or Cobb retractor. An assistant gently rotates the laminae toward the hinge side using a similar instrument. The dura is gently detached from the overlying flavum ligament with a Penfield dissector. In cases with myeloradiculopathy, a 1 mm Kerrison rongeur is used for individual nerve root decompression *via* foraminotomy.

Extension of the open side of the laminoplasty will establish the titanium miniplate sizes to be used. The spinous processes are removed. The door is kept open by placing titanium spacers. To fix the spacers to the lateral masses we recommend drilling a small burr-hole first. The starting point in the lateral mass is 1 mm medial and cephalad to its midpoint. We used a drill/guide and finally 3 mm titanium screws. Drilling the laminae screw holes first to avoid spinal cord compression during screw placement. We used a manual drill/guide for each screw. The spacer is fixed to the corresponding lamina with two screws. The steps are repeated for each level. The underlying dura must be laterally exposed along the entire open side trough (Figs. **1** and **2**).

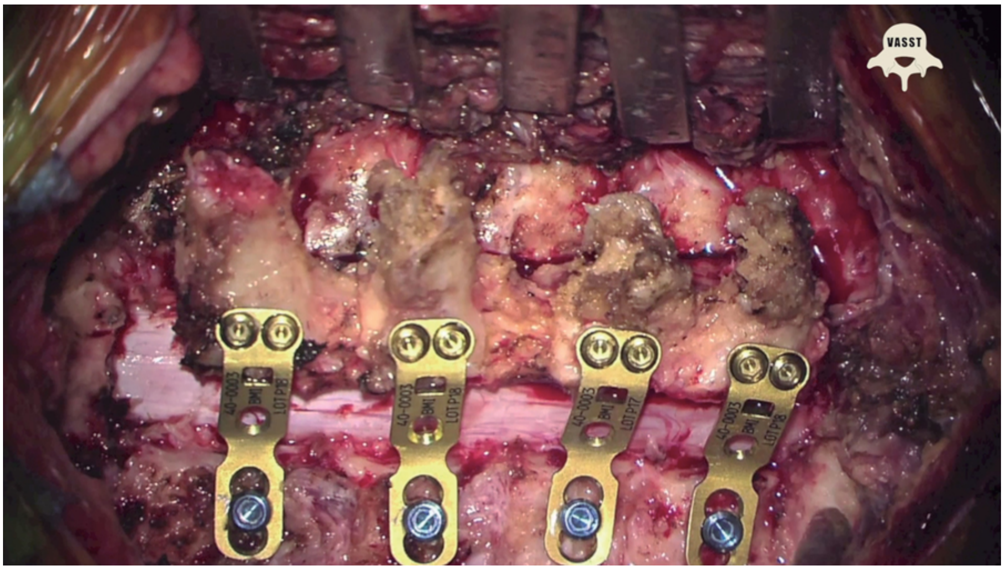

Fig. (1). Intraoperative photograph shows the underlying dura exposed along the entire open side trough.

CHAPTER 18

Subaxial Translaminar Screw Fixation

Jae Taek Hong[1,*]

Department of Neurosurgery, St. Vincent's Hospital, Catholic University of Korea, Korea

Keywords: Cervicothoracic junction, Instrumentation, Laminar screw video, Translaminar technique.

GENERAL ASPECTS

Cervical posterior instrumentation has been greatly advanced over the past two decades. Rigid screw fixation techniques have replaced wiring techniques to reduce motion, maintain solid graft interfaces and increase fusion rate. In the modern era, a number of rigid internal screw fixation techniques have been developed, greatly improving our ability to stabilize the vertebral column segmentally [1]. Recently, many techniques have been described for posterior cervical instrumentation. Although lateral mass screws are relatively constructs to avoid neurovascular structures, they sometimes result in failure due to osteoporosis, screw loosening or avulsion, particularly at the level of C7 where the dimension of lateral mass is usually thin and steep in angle [2].

Cervical pedicle screw has been recommended as an alternative to overcome these limitations. Pedicle screw fixation has been reported to be most biomechanically stable when performed through a posterior-only approach. However, pedicle screw instrumentation can be technically difficult in the cervical spine and potentially dangerous, as the cervical pedicle is small and is closely surrounded by delicate neurovascular structures: laterally by the vertebral artery, medially by the spinal cord, and vertically by adjacent nerve roots [3].

* **Correspondence to Jae Taek Hong:** Department of Neurosurgery, St. Vincent's Hospital, Catholic University of Korea, Korea; E-mail: jatagi15@gmail.com

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Recently, intralaminar screws have been used as a potentially safer alternative to traditional fusion constructs involving fixation of C2 and the cervicothoracic junction including C7 [2, 4].

The intralaminar screw method is useful for avoiding vascular injuries, especially when there is a high riding vertebral artery (HRVA) around C2 or the V2 segment of VA enter into the C7 transverse foramen. This technique has two important advantages over currently used surgical options: first, it is simpler and does not require the use of any navigational instruments, and second, it is not limited by the VA position. Therefore, the potential patient population that could benefit from this procedure is large.

INDICATIONS

Indications for surgery include cervical spine instability due to trauma, tumor and infection. Patients who need posterior augmented fusion for pseudoarthrosis can be a good indication for subaxial cervical laminar screw fixation.

SURGICAL TECHNIQUE

First of all, length of intralaminar screw should be assessed on axial CT imaging preoperatively and measured from a defined entry point in the spinolaminar junction to the junction between lamina and lateral mass. The procedure of laminar screw placement into the subaxial spine is very similar to the technique described by Wright for placement of C2 laminar screws [4].

After dorsal exposure of the spinous process and lamina, the slope angle of the lamina is measured. A high-speed drill is used to open a small starter hole at the spinolaminar junction. The entry points for the intralaminar screws are staggered at the base of the spinous processes so that the two screws do not collide with each other or violate the laminar cortex in the case of bilateral C7 crossing 2 laminar screw fixation. A drill or gearshift is then used to create a tract in the contralateral lamina, using the slope of the contralateral lamina as a guide. The laminar screw trajectory should be made along the thickest part of the lamina, around the middle of the lamina at C2 and the junction between the middle and inferior third of the lamina at C7 [5]. Screw trajectory might be angled dorsally to avoid violation of the ventral laminar cortex. The screw tract is then palpated with a ball-tipped probe to ensure that there is no violation of the ventral cortex and spinal canal, and tapped with a 3.0mm tap. Polyaxial screws (3.5 or 4.0-mm diameter) are inserted along the same trajectory without radiographic monitoring. The screw-head remains at the junction of the spinous process and lamina on one side of the vertebra, with the remainder of the screw within the lamina on the other side. The polyaxial heads are left exposed to allow movement and connect the rod. A specialized lateral connector can be used when it is difficult to connect the rod directly to the screw head.

COMPLICATIONS

There are two major concerns about the subaxial cervical laminar screw. First, one is the risk of damage to the ventral spinal cord, which is the main risk associated with placement of translaminar screws [6]. If this is a concern, a slightly more dorsal trajectory can be used to avoid ventral penetration into the spinal canal. In this case, even if penetration of the dorsal cortex occurs, we have not experienced any associated clinical consequences. Using gear-shift technique, surgeon can avoid the ventral cortical breach and violation into the spinal canal. And also, the dorsal laminar surface serves as a guide for the screw trajectory for C7 intralaminar screw placement. However, the most important step to prevent ventral cortical breach is not to make an entry point anterior to the spinolaminar junction.

A second cause of concern is that the anatomy of the C7 posterior elements may prohibit successful placement of 3.5 or 4-mm diameter screw. Anatomical studies showed that the C7 laminae of women are smaller than those of men and some C7 laminae are not thick enough to afford 3.5 or 4-mm diameter screw. And also, C7 intralaminar screw cannot be used in cases with laminar fracture and in cases that need C7 laminectomy. So, preoperative radiographic evaluation is necessary to choose optimal fixation technique [3, 7].

IMPORTANT ISSUES OF CERVICAL LAMINAR SCREW

The surgeon should remember the anatomical difference between the lamina of C2 and C7. Anatomically, C7 is very similar to thoracic vertebrae, in which

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CHAPTER 19

Mini - Videoassisted Transthoracic Approach

Matias Nicolas[2], Federico Landriel[*, 1], Santiago Hem[1], Claudio Yampolsky[1], Eduardo Vecchi[1], David Smith[2]

[1] *Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina*

[2] *Department of General Surgery, Thoracic Surgery Division, Hospital Italiano, Buenos Aires, Argentina*

Keywords: Mini-TTA technique, Mini-TTA surgical video, Transthoracic approach surgical video, Thoracic discectomy video.

GENERAL ASPECTS

The success of minimally invasive thoracic surgery in lungs and mediastinum has improved endoscopic video systems and the development of endoscopic instruments, allowing surgeons to apply these technologies for a less aggressive approach.

Mini-thoracotomy video assisted surgery and video-assisted thoracoscopic surgery (VATS) are two minimally invasive approaches for the thoracic spine. Both are appealing alternatives to thoracotomy for thoracic spine approach due to their known benefits of reducing surgical trauma with less postoperative pain, improving cosmesis and providing effective exposure with equivalent results as conventional anterolateral thoracotomy.

INDICATIONS

- Tumors
- Fractures (myelopathy/instability)
- Discitis/osteomyelitis
- Anterior epidural abscess

[*] **Correspondence to Federico Landriel:** Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina; E-mail: fedelandriel@gmail.com

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- Symptomatic thoracic disc herniation
- Sympathectomy
- Ossification of the posterior longitudinal ligament

RELATIVE CONTRAINDICATIONS

- Pleural empyema history
- Patient not suitable for single lung ventilation

SURGICAL TECHNIQUE

Under general anesthesia, a double-lumen endotracheal tube is placed to allow for single-lung ventilation and deflation of the non-ventilated lung and thus, improve surgical field visualization.

The patient is positioned in a left-lateral decubitus position with an axillary roll to prevent lesions to the brachial plexus. The operation table has a convex bending to widen the intercostal space. The surgeon and assistant stand facing patient's chest and the approach is generally performed from the right side. The patient is held in position by soft pads in the neck and buttocks behind and in the iliac crests anteriorly to allow intraoperative tilted movement, if necessary. Somatosensory and motor evoked potentials are monitored during the procedure.

A metallic marker is placed in the head of the rib of the desired surgical level. A thoracoscopic portal is placed for the camera. A 1 cm incision is made in the junction of the 7^{th} intercostal space and the posterior axillary line, allowing the surgeon to localize exactly the correct place for the mini-thoracotomy, identifying the compromised spine level, by counting the ribs intrathoracically under scope visualization and corroborating under live fluoroscopy. The entire procedure is performed with a working 30-degree 10 mm scope.

A 4 cm intercostal incision is made along the superior costal margin between the anterior border of the latissimus dorsi and the posterior border of mayor pectoralis, preserving both muscles (Fig. **1**). The serratus anterior muscle is divided accessing to the thoracic cavity. A small rib retractor is used depending on patient´s characteristics.

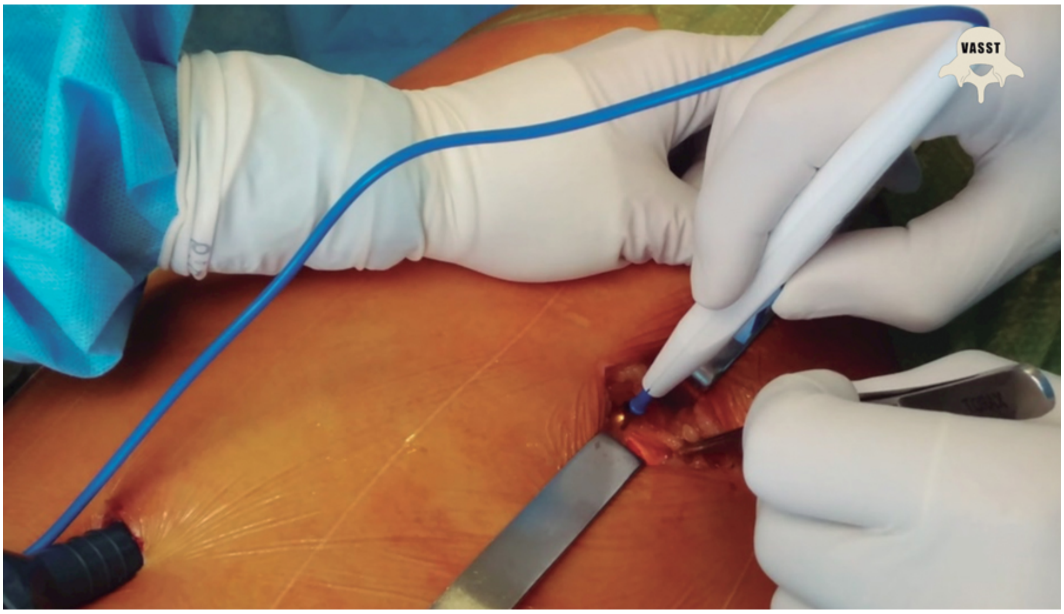

Fig. (1). Intraoperative photograph showing the intercostal incision along the superior costal margin between the anterior border of the latissimus dorsi and the posterior border of pectoralis major.

The parietal pleura is opened with monopolar cautery under direct visualization through the scope.

Discectomy

The parietal pleura is incised at the affected spine level. Segmental vessels are ligated with hem-o-lok® clips, facilitating exposure and minimizing blood loss (Fig. **2**). Under microscope magnification, the rib head and radiate ligaments are detached and removed from its costovertebral articulation and lateral aspects of the involved vertebral bodies are exposed. The pedicle of the lower vertebral body is identified and its cranial half is removed with a high-speed drill. A trough is drilled between the inferolateral part of the cranial vertebral body, and the superolateral portion of the caudal vertebra (Fig **3**). The posterior longitudinal ligament is identified and opened as required. A standard discectomy is performed. Once the dura is exposed, the herniated disc material is removed with careful curettage from the sac to the created trough (Fig. **4**).

CHAPTER 20

Minimally Invasive Transpedicular Approach

Lee A. Tan[1,*], Ippei Takagi[2], Harel Deutsch[1]

[1] *Department of Neurosurgery, Rush University Medical Center, Chicago, IL, USA*

[2] *Legacy Spine and Neurological Specialists, Little Rock, Arkansas, USA*

Keywords: Minimally invasive, Spine surgery, Transpedicular approach, Thoracic video.

GENERAL ASPECTS

Many pathological processes can affect the vertebral column and cause ventral compression of the thoracic spinal cord. Surgical approach to the anterior thoracic spinal canal and ventral spinal cord can be challenging. Simple laminectomy had been used historically to address these thoracic pathologies and was met with high rates of postoperative neurological deterioration due to spinal cord manipulation. Thus, various posterolateral and anterior approaches including transpedicular [1], costotransversectomy [2], lateral extracavitary [3], transthoracic-transpleural [4] and transthoracic-retropleural [5] were developed to avoid spinal cord manipulation and improve clinical outcome. Since the introduction of these newer techniques, there has been a sharp decline in postoperative neurologic morbidity associated with these thoracic spine pathologies. However, many of these established approaches are still associated with significant procedure-related morbidities including pleural effusion and post-thoracotomy pain from transthoracic approaches, or large skin incision and musculocutaneous flap with disinsertion of paraspinal musculatures from open posterolateral approaches.

As minimally invasive surgery (MIS) technology and techniques are becoming more mature and advanced, the MIS transpedicular approach has been used by many surgeons to address various thoracic spine pathologies with success [6 - 10].

* **Correspondence to Lee A. Tan:** Department of Neurosurgery, Rush University Medical Center, Chicago, IL, USA; E-mail: Lee_tan@rush.edu

Federico Landriel and Eduardo Vecchi (Eds)

With proper patient selection, careful attention to detail and meticulous surgical techniques, MIS transpedicular approach can be an extremely valuable tool for spine surgeons to treat anterior thoracic spine pathologies with minimal procedure-related complications. This chapter is aimed to illustrate the MIS transpedicular technique with discussion of surgical nuances related to this approach in order to help spine surgeons to minimize potential complications.

INDICATIONS AND CONTRAINDICATIONS

MIS transpedicular approach may be used to address pathologies such as soft, laterally located thoracic disc herniation, ventral spinal cord herniation [8], Pott's disease [9], spinal metastasis with cord compression [7], as well as thoracic discitis and epidural abscess [10]. The MIS transpedicular approach can be especially useful in patients with medical co-morbidities who would not tolerate thoracotomy or extensive open posterolateral procedures. The MIS approach used for spinal cord decompression in the setting of metastatic disease also allows for quicker wound healing and thus faster initiation of adjuvant treatments such as chemotherapy and radiation.

The contraindications for this approach are similar to any other surgery; they mainly include significant cardiopulmonary co-morbidities that prevent patients from undergoing general anesthesia and severe coagulopathy or thrombocytopenia. In addition, large centrally located calcified thoracic disc herniation may be best addressed *via* anterior or more lateral approaches for more direct visualization of anterior dura and to minimize the need of spinal cord manipulation.

SURGICAL TECHNIQUE

The patient is brought into the operating room and undergoes general endotracheal anesthesia. Continuous blood pressure monitoring, intraoperative somatosensory evoked potential (SSEP) and motor evoked potential (MEP) monitoring are set up. Care is taken at all times to maintain adequate mean blood pressure (we usually keep MAP ~80 mmHg).

The patient is then positioned prone on a radiolucent open Jackson table with all pressure points well-padded. The pedicle of the intended level with known pathology is identified using fluoroscopy in both anterior-posterior and lateral planes. A 3-cm long incision is made about 2-cm lateral to the midline on the side with more severe spinal cord compression and most pathology. The incision is carried through the posterior thoracic fascia with monopolar cautery until the underlying paraspinal muscles are visualized. Blunt finger dissection is then used to palpate the transverse process and the proximal rib. Sequential dilators were then introduced and docked at an angle of approximately 30 degrees toward the midline. A tubular retractor of appropriate size (we usually use 22-mm tubes) is placed and secured to the operating table with the retractor holder.

The microscope is then brought into the operative field. Any residual soft tissue overlying the bony structures is removed in the usual fashion for MIS procedures. A high speed drill is used to remove the transverse process, facet, lateral lamina, and thoracic pedicle at the intended level. The spinal cord is identified and the exiting thoracic nerve root retracted or resected if necessary to gain access to the vertebral body and disc space to address the corresponding thoracic pathologies.

In the setting of spinal metastasis with ventral cord compression, the high-speed drill can be used to perform a partial vertebrectomy. A pituitary forceps was used to remove the tumor from the vertebral body in a piecemeal fashion. Epidural tumor can be resected by pushing tumor into the vertebrectomy defect using down-biting curettes. Because of the posterolateral trajectory, direct visualization of the lateral aspect of the ventral spinal canal can be obtained. Indirect dissection using down-biting curettes can facilitate the decompression of midline and contralateral ventral surface. If extensive compression exists in the contralateral side, bilateral transpedicular approach can allow complete decompression of the ventral canal. When bilateral transpedicular approach is used, however, it may be necessary to place instrumentation to maintain spinal stability.

After addressing the intended thoracic pathology, the posterior thoracic fascia can be closed with simple interrupted sutures. The subcutaneous tissue and skin can be closed with inverted sutures and skin glue.

CHAPTER 21

Costotransversectomy Approach

Basem I. Awad[1, 2], Edward C. Benzel[3], Michael P. Steinmetz[1, *]

[1] *Department of Neurological Surgery, Case Western Reserve University School of Medicine, MetroHealth Medical Center, Cleveland, OH, US*

[2] *Department of Neurological Surgery, Mansoura University School of Medicine, Mansoura, Egypt*

[3] *Department of Neurosurgery, Neurological Institute, Center for Spine Health, Cleveland Clinic, Cleveland, OH, US*

Keywords: Costotranversectomy approach, Costotransversectomy Video, Posterior Approach.

GENERAL ASPECTS

The surgical management of pathologies involving the thoracic spine can be challenging. The thoracic spine may be approached ventrally through a variety of techniques. Thoracotomy based approaches provide direct anterior access and visualization of the vertebral bodies and ensure complete spinal canal decompression. However, the concurrent approach related morbidities can be significant such as pulmonary contusion, atelectasis, pleural effusion, hemothorax, and chylothorax [1 - 3]. Consequently, some surgeons have advocated the dorsolateral approaches, such as costotransversectomy (CTE), to avoid entrance into the pleural cavity and enable ventral decompression with simultaneous posterior access for segmental fixation through the same single incision.

INDICATIONS

CTE is indicated for the treatment of several spinal disorders including thoracic disc disease, tumors, infection, trauma, and deformity. It allows the surgeon to simultaneously expose both the ventrolateral and dorsal aspects of the spine

* **Address correspondence to Michael P. Steinmetz:** Department of Neurological Surgery, Case Western Reserve University School of Medicine, MetroHealth Medical Center, Cleveland, OH, US; E-mail: Author msteinmetz@metrohealth.org

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through a single incision. Accordingly, it permits ventral decompression and reconstruction (if required) in conjunction with dorsolateral fixation. Furthermore, CTE allows the surgeon to protect the neural structures during decompression by mobilizing the abnormal tissue away rather than toward the spinal cord.

SURGICAL TECHNIQUE

A. Positioning

CTE is performed most commonly with the patient in the prone position. However, other surgeons prefer the three-quarter prone position. Typically, the arms are positioned forward, but if performed in the upper thoracic spine, the arm on the ipsilateral side of the CTE may be placed down alongside the thorax. Following incision, the scapula thus is able to fall away from the spine improving exposure. The Jackson table provides optimal padding and positioning. The patient should be safely secured to the table and all pressure points should be checked after positioning.

B. Incision

Following positioning, the authors locate the pathology *via* x-ray or fluoroscopy. Once the location has been confirmed and marked, a variety of incisions may be utilized. The authors typically utilize a curvilinear skin incision centered at the index disc space. This incision permits adequate lateral exposure of the transverse process and proximal rib. Additionally, a midline vertical incision with a horizontal "T" directly placed over the aimed rib can be used. This also provides adequate exposure, but may have an increased incidence of wound breakdown at the site of the "T".

C. Dissection

Following skin incision, a plane is created down to the thoracic fascia using electrocautery. The authors prefer subperiosteal dissection of the paraspinal musculature from the spinous processes, lamina and transverse processes of the index level and at least one level cranial and caudal. Next, the muscular insertion of the paraspinal muscles mass may be dissected, thus elevating the musculature off the proximal rib (3cm) and spine. With retractors in place, the surgeon is able to visualize the ipsilateral proximal rib, transverse process, facet joint and lamina.

D. Decompression

The authors prefer to first remove either the entire lamina or hemilamina at the index level. This permits early exposure of the dura. Next, the index transverse process is completely removed to expose the rib, facet joint and pedicle. The facet joint may be completely resected to fully expose the index pedicle, which may be removed flush to the vertebral body. The proximal 3-4 cm of rib may be dissected and transected with care not to enter the pleural space. It may then be traced to the vertebral body and disarticulated at the rib head with the use of a Cobb elevator. At this point, the lateral vertebral body may be dissected in a subperiosteal plane with care not to injure the segmental vessel. The lung and pleura are then retracted laterally. However, care must be taken not to enter the pleural cavity. For vertebrectomy, the superior and inferior disc spaces are first identified. Thorough discectomy must be performed at both levels so as to fully protect the endplates at the adjacent levels. The exiting nerve root is sacrificed proximal to the dorsal root ganglion. The intervening vertebral body is then removed. This may be accomplished with a high-speed drill, osteotomes, and/or rongeurs. Decompression is carried into the disc spaces above and below and ventrally. Ventral bone is typically left in place as well as a thin wall of cortex along the dorsal spine immediately ventral to the spinal cord. The vertebrectomy is carried towards the contralateral pedicle and continued until it is large enough for bone graft or cage insertion. Lastly, the posterior cortex of the vertebral body is gently depressed away from the spinal cord.

After controlling the epidural bleeding, the graft material of choice is inserted. The removed rib can be used as structural autograft or alternately morselized for use with expandable cages. If dorsal instrumentation is used, screws are typically placed prior to vertebrectomy. A temporary rod may be placed prior to completion of the vertebrecotmy to prevent movement of the spine during decompression. Following graft or cage placement, rods are placed across the dorsal instrumentation along with compression if desired.

CHAPTER 22

Lateral Extracavitary Approach

Basem I. Awad[1,2], Michael P. Steinmetz[1,*]

[1] *Department of Neurological Surgery, Case Western Reserve University School of Medicine, MetroHealth Medical Center, Cleveland, OH, USA*

[2] *Department of Neurological Surgery, Mansoura University School of Medicine, Mansoura, Egypt*

Keywords: Dorsolateral approach, Lateral extracavitary video, LECA surgical technique.

GENERAL ASPECTS

The surgical management of pathology involving the ventral aspect of the thoracic and upper lumbar spine is typically challenging. Thoracotomy provides direct ventral exposure of the spine and spinal cord; however, the approach related morbidities could be markedly significant [1, 2] while a separate dorsal approach may be required for instrumentation. The lateral extracavitary approach (LECA) is a dorsolateral approach that provides lateral and ventral access to thoracic and upper lumbar spine without entrance into the pleural cavity. Dorsal fixation is possible through the same incision.

LECA was first used by Capener for the treatment of Pott's disease and reported later by Seldon in 1935, followed by Capener himself in 1954 [3]. In 1960, Hulme described the same approach as an alternative to laminectomy for ventral thoracic pathology because of the poor outcome and inadequate exposure of ventral spine elements [4]. Larson *et al*. [5] modified this approach in 1976 by describing a trajectory ventral to the paraspinal muscles, which are reflected medially instead of transversely divided as described previously by Capener. During the past 30 years, LECA, along with modifications, has been used in the management of

[*] **Address correspondence to Michael P. Steinmetz:** Department of Neurological Surgery, Case Western Reserve University School of Medicine, MetroHealth Medical Center, Cleveland, OH, USA; E-mail: msteinmetz@metrohealth.org

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many thoracic and lumbar spine disorders due to infection, trauma, neoplasm, and degenerative disease [6 - 9]. Recently, LECA has been modified in a cadaver study to be used *via* a minimally invasive retractor system for deformity correction [10] and in management of thoracic disc herniation [11, 12].

INDICATIONS

LECA is indicated for the treatment of ventral pathology of the thoracic and lumbar spine, especially when dorsal instrumentation is required along with ventral decompression. This may include tumor, osteomyelitis and fractures [6 - 9]. In more extensive pathology, this approach can be performed in a bilateral fashion for adequate ventral exposure [13]. Bony interbody fusion can also be performed after decompression as well as dorsal fixation.

SURGICAL TECHNIQUE

Positioning

LECA is commonly performed with the patient prone and arms at the side. However, other surgeons prefer the three-quarter prone position [6]. The Jackson table provides optimal padding and positioning. The patient should be safely secured to the table and all pressure points must be checked after positioning.

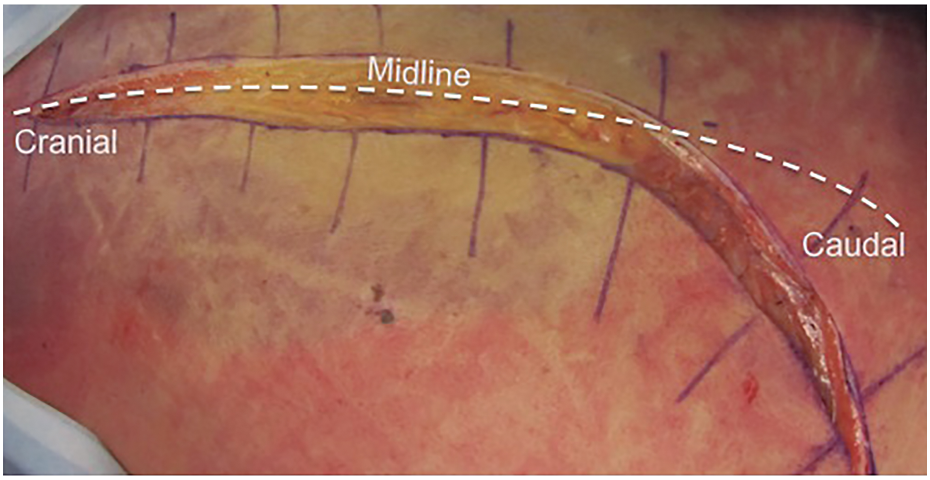

Fig. (1). The image showed the typical hockey stick-type incision which extends two to three spinal levels above and below the pathology with the caudal limb angling toward the pathological side.

Incision

Following positioning, appropriate localization *via* x-ray or fluoroscopy of the lesion is crucial. Once the location has been confirmed and marked, a variety of incisions may be utilized. The authors typically utilize a hockey stick-type incision (Fig. **1**). The midline incision extends two to three spinal levels above and below the pathology with the caudal limb angling toward the pathologic side.

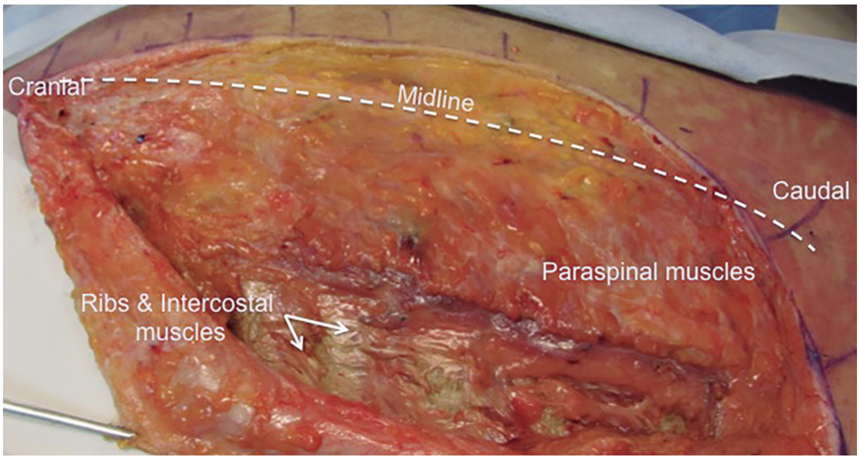

Fig. (2). The image shows the dissected paraspinal muscles and the rib cage.

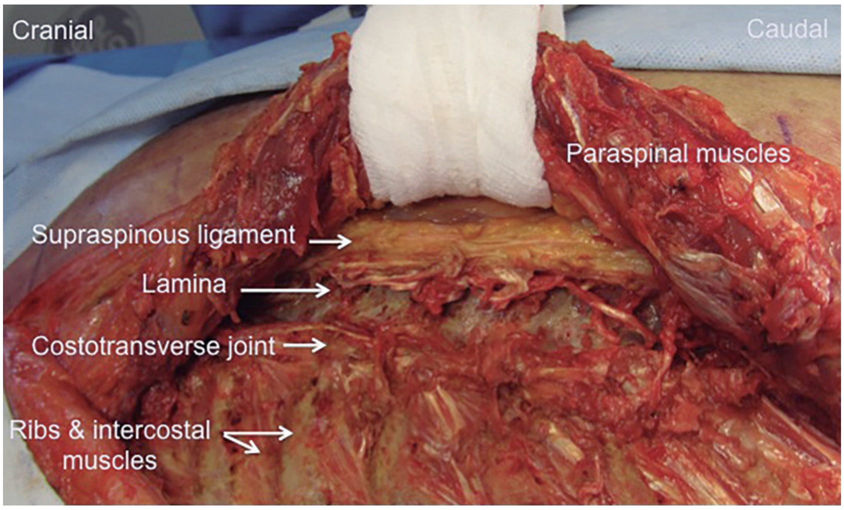

Fig. (3). The images show the paraspinal muscles wrapped and elevated in a laparotomy pad and then retracted medially.

CHAPTER 23

Minimally Invasive Anterior Endoscopic Thoracic Discectomy

Noel I. Perin*

Department of Neurosurgery, NYU Langone Medical Center, New York, USA

Keywords: Thoracoscopy, Thoracic disc herniation video, Tubular retractor, Rib resection.

GENERAL ASPECTS

Symptomatic thoracic disc herniation (TDH) is an uncommon condition with significant treatment risks. A variety of surgical approaches can be utilized, each with their advantages and disadvantages [1, 2]. Over the past decade we have found several techniques to be successful at preventing complications, including the use of an anterior minimally-invasive approach which combines the advantages of thoracoscopy, and tubular retractor surgery [3 - 5] and allows the use of the operating microscope [10].

INDICATIONS

- Large central calcified thoracic disc herniations with the dura draped around the sides of the herniation [9].
- Patients with paracentral disc herniations with significant neurological deficits where a poster-lateral approach may require manipulation of the cord.

CONTRAINDICATIONS

- Prior thoracotomy and patients with a history of empyema and/or pleurodesis may have significant pleural adhesions and may not be suitable for this approach.

* **Address correspondence to Noel I. Perin:** Department of Neurosurgery, NYU Langone Medical Center, New York, USA; E-mail: noel.perin@nyumc.org

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- This approach may not be feasible in cases of disc herniations above T3 and in morbid obesity.

SURGICAL TECHNIQUE

In the operating room, the patient was intubated with a double-lumen endotracheal tube and positioned in the lateral decubitus position with the table flexed to widen the intercostal space, or a bolster placed under the chest. Cross table antero-posterior x-rays obtained and the metallic marker placed preoperatively in the head of the rib identified. The appropriate disc level was localized. For thoracoscopy-guided tubular retractor approach, the working port/mini-thoracotomy site was placed in the intercostal space overlying the appropriate disc space, and slightly behind the posterior axillary line (Fig. **1**).

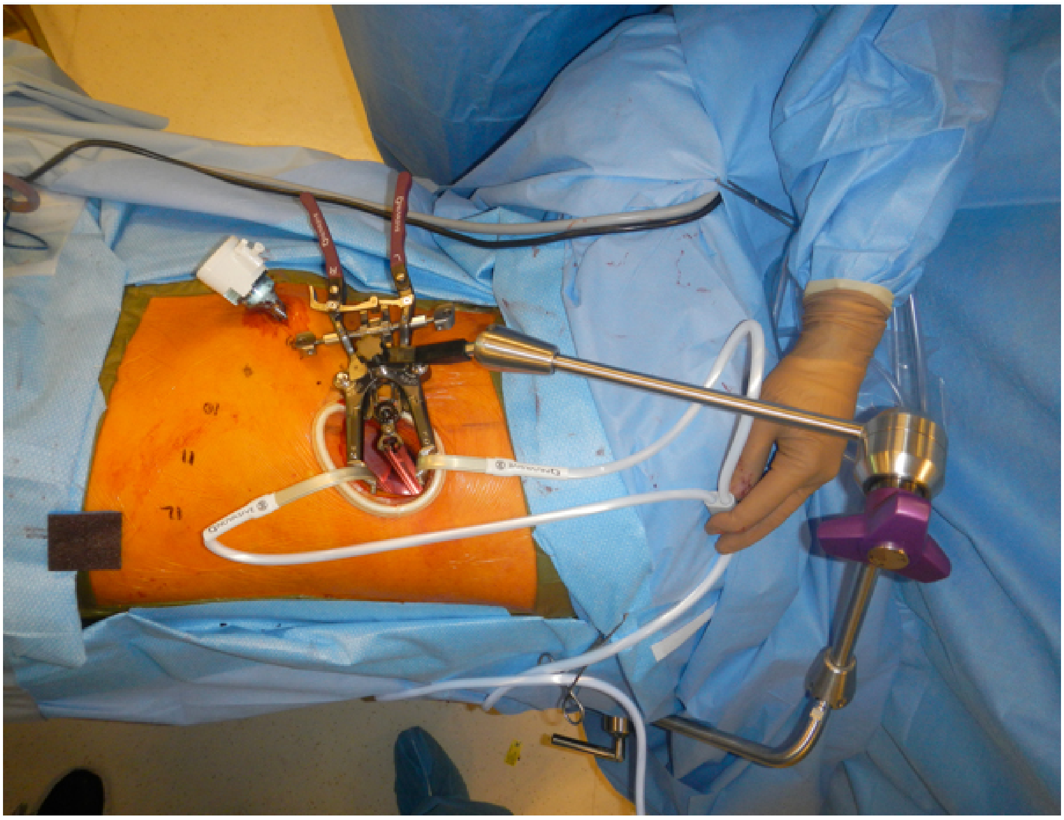

Fig. (1). Intraoperative photograph shows a tubular retractor (XLIF, Nuvasive®)placed in the intercostal space overlying the appropriate disc space, and slightly behind the posterior axillary line.

In this combined approach, an exploratory thoracoscopy was performed *via* two 5 mm ports using a 5 mm zero-degree angled endoscope. An exploratory thoracoscopy was carried out, minor pleural adhesions were released and the disc space identified from within the chest cavity by counting the ribs and placing a K-wire in the disc and crosstable x-rays were obtained to identify and mark the disc space. A endoscopic fan retractor may be utilized to retract the lung and great vessels to expose the spine (Fig. **2**). The harmonic scalpel was then used to open the parietal pleura overlying the disc space and rib, and if necessary the adjacent segmental vessels were dissected free, coagulated, and divided. Following these preparatory steps, the incision over the working port was enlarged to approximately 3-5 cm, and a tubular retractor (XLIF, Nuvasive®) was safely deployed to the disc space under continuous endoscopic visualization. More recently, we started removing a 3-cm segment of rib at the working port to minimize the risk of rib fracture and intercostal neuralgia from forces generated by the retractor blades. (This segment was reattached with titanium mini-plates at the end of the operation).

Once the tubular retractor was docked on the disc space, the third blade was opened anteriorly, with necessary additional plastic shims used as to protect the lung. The microscope was then brought into position. The head of the rib was detached from its costovertebral articulation, and the rib was drilled 2 cm from the head. The rib head was removed in one piece and saved for possible bone grafting. The posterior aspects of the disc space and adjacent vertebral bodies were exposed together with the pedicle of the lower vertebra. With a high-speed coarse diamond burr, drilling was performed straddling the disc space from the posterior third of the vertebral bodies toward the spinal canal and drilling the rostral half of pedicle of the lower vertebra. Drilling was carried towards the spinal canal until a thin cortical shell with the herniated and/or calcified disc material was left against the anterior spinal canal. The thin cortical shell of the pedicle remaining over the lateral spinal canal was removed to identify the thecal sac. The shelf of bone and disc material remained on the anterior spinal canal detached rostral and caudal from the disc herniation, and the attached disc was gently freed from the dura and pulled into the trough created anteriorly. The decompression was extended rostrally and caudally as necessary and across the

CHAPTER 24

Minimally Invasive Posterolateral Thoracic Discectomy

Albert P. Wong*, **Youssef J. Hamade , Zachary A. Smith, Richard G. Fessler**

Department of Neurosurgery, Rush University Medical Center, Chicago, Illinois, USA

Keywords: Discectomy, Endoscopic, Minimally Invasive, Thoracic disc video.

CASE PRESENTATION

A 32 year-old right handed female had a history of mid-back pain with radiation around the right side of the chest for several years. She describes having bilateral lower extremity pain and paresthesias, as well as difficulties with balance on ambulation.

She denies any weakness in her extremities, or difficulties in control of bladder or bowels. She tried medical management without any improvement in her symptoms.

On physical exam, the patient is strong throughout without sensory deficits. Her reflexes are 3+ in bilateral lower extremities. There is no clonus, Babinski sign or Hoffman's sign on examination.

IMAGING STUDIES

An MRI of the thoracic spine without contrast demonstrates a right paracentral T8-T9 disc herniation with moderate cord compression. There is an additional, smaller T11-12 disc herniation without significant canal stenosis. There is no evidence of edema in the spinal cord on imaging (Fig. **1**).

* **Address correspondence to Albert P. Wong:** Department of Neurosurgery, Rush University Medical Center, Chicago, Illinois, USA; E-mail: a-wong@fsm.northwestern.edu

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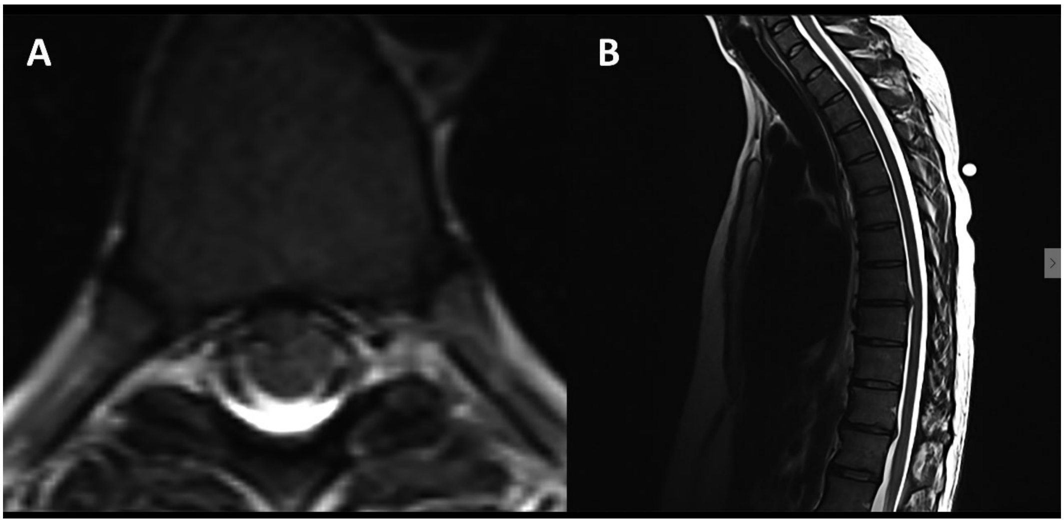

Fig. (1). A. T2 axial MRI and B. T2 sagittal MRI of the thoracic spine demonstrates a right paracentral T8-T9 disc herniation with compression of the spinal cord. There is no evidence of spinal cord edema.

SURGICAL TECHNIQUE

Positioning

The patient is turned prone onto a radiolucent operating table on top of chest rolls with the arms placed cephalad, away from the surgical site. All bony prominences and vulnerable pressure points are padded. The skin is shaved and cleaned with alcohol. The midline is marked with a skin marker over the prominent spinous processes and a parallel skin incision is drawn 1.5 cm ipsilateral (right) of the midline (Fig. **2**). Once the skin incision is localized over T8-T9, sterile surgery drapes are placed in wide fashion around the operative field. The skin is scrubbed with betadine solution for five minutes, then "painted" with alcohol and allowed to dry spontaneously. The skin incision site is remarked with a sterile skin marker after the alcohol has dried completely.

The surgical area is finally prepped with an iodine and alcohol solution (DuraPrep™, 3M™). Sterile towels are used to border the sterile surgical field followed by a sterile antimicrobial impregnated sterile film (Ioban™, 3M™). The remaining surgical field is isolated with sterile drapes in standard fashion. Confirmation of the T8-T9 disc space is localized by counting vertebral bodies with "live" fluoroscopy in the lateral position from the sacrum up to T8-T9 and the surgical site is confirmed with anterior-posterior fluoroscopy by counting ribs. The surgical level is marked with a spinal needle (Fig. **3**).

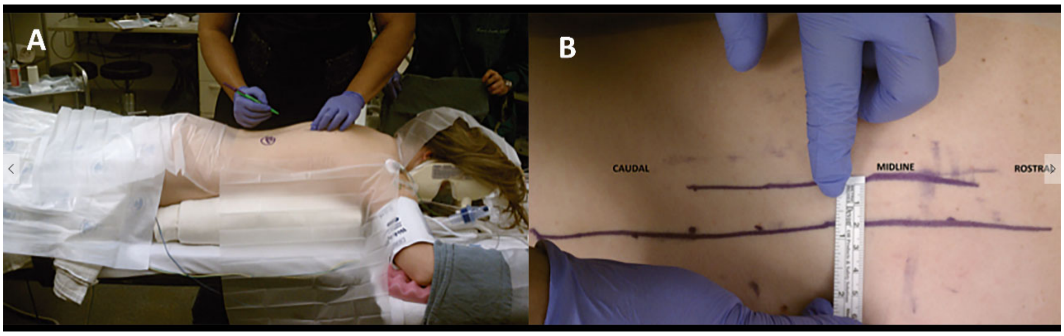

Fig. (2). The patient is positioned prone on top of chest rolls on a radiolucent operating table. B. Magnified view of the incision drawn fifteen millimeters lateral to the midline, ipsilateral to the lesion (right paracentral T8-T9 disc herniation).

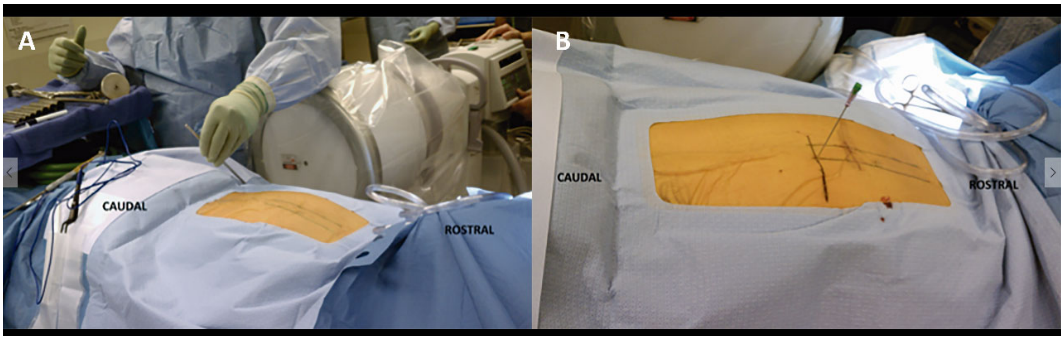

Fig. (3). A. The initial tubular dilator is used as a metallic marker to localize the surgical level (T8-T9) under "live" fluoroscopy in the lateral position. B. The surgical level is identified by counting from the sacrum up to the T8-T9 disc space with lateral fluoroscopy and confirmed by counting ribs with anterior-posterior fluoroscopy. A spinal needle is used to clearly mark the surgical level.

Intraoperative Neurophysiologic Monitoring

Somatosensory evoked potentials and motor evoked potentials are placed during general anesthesia prior to final positioning of the patient.

Incision

The original skin incision was marked and localized with fluoroscopy fifteen millimeters ipsilateral to the midline. The incision is infiltrated with a

CHAPTER 25

Minimally Invasive Retropleural Corpectomy

Albert P. Wong*, Tarek Y. El Ahmadieh, Nader S. Dahdaleh , Richard G. Fessler

Department of Neurosurgery, Rush University Medical Center, Chicago, Illinois, USA

Keywords: Corpectomy video, Direct lateral, Minimally Invasive, Retropleural.

CASE PRESENTATION

A 54 year-old right handed female with a history of Stage IV breast cancer and left mastectomy presents with "pelvic pain" and radiating pain into her bilateral lower extremities is admitted in the past month. The radiating pain is described as bilateral burning sensation into the groin. She also describes mild weakness in her lower extremities and trouble with ambulation due to imbalance. She denies any difficulties in control of her bladder or bowels.

On physical exam, the patient is strong in her bilateral upper extremities without sensory deficits. Her bilateral lower extremities demonstrate proximal strength of 4- and distal strength of 4+. Her reflexes are 3+ in bilateral lower extremities, left greater than right foot clonus, and there is presence of bilateral Babinski's. Hoffman's sign is not present.

IMAGING STUDIES

A CT of the thoracolumbar spine demonstrates a severe, pathologic compression fracture of the T12 vertebral body. An MRI of the thoracolumbar spine with and without contrast demonstrates multiple enhancing osseous lesions throughout the cervical, thoracic, and lumbar spine. Most significantly, there is an enhancing mass which involves the T12 vertebral body with dorsal extension causing severe compression of the thoracic spinal cord. There is evidence of spinal cord edema on MRI (Fig. **1**).

* **Address correspondence to Albert P. Wong:** Department of Neurosurgery, Rush University Medical Center, Chicago, Illinois, USA; E-mail: a-wong@fsm.northwestern.edu

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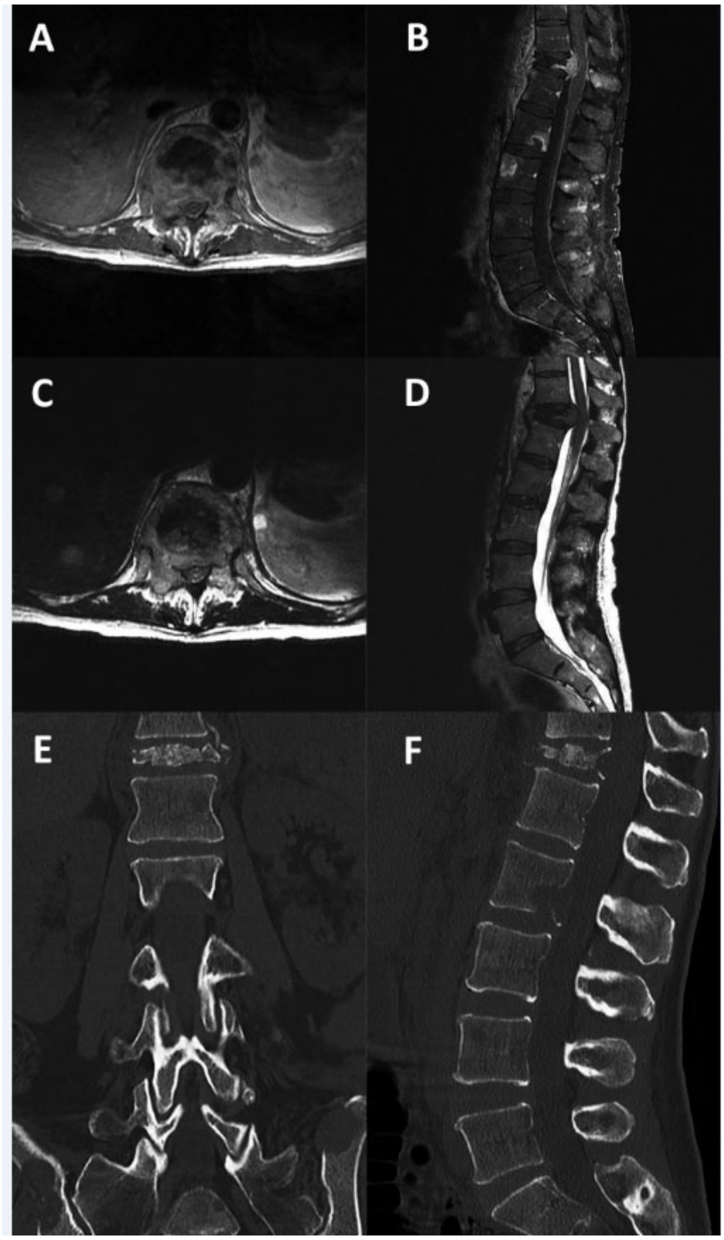

Fig. (1). A and B. T1 axial and T1 sagittal MRI with contrast shows an enhancing T12 vertebral body lesion with dorsal extension and compression of the thoracic spinal cord. C and D. T2 axial and T2 sagittal MRI of the thoracolumbar spine demonstrates impaired CSF signal around the spinal cord. E and F. Coronal and sagittal CT of the thoracolumbar spine demonstrates the severe pathologic compression fracture of T12.

SURGICAL TECHNIQUE

Positioning

The patient is intubated under general anesthesia and turned into the lateral position, left side up. The greater trochanter is placed directly over the "breakpoint" of the operating table. Both the head and foot of the table are flexed toward the floor to increase the working space between the ribs and the pelvis. The upper leg is flexed to decrease tension on the iliopsoas muscle.

The patient is secured to the operating table with surgical tape at the shoulder, hip, and legs, followed by inflation of the beanbag for additional support (Fig. **2**) [1]. All bony prominences and vulnerable pressure points are padded.

The surgical site is cleaned with alcohol and fluoroscopy is used to localize over the T12 vertebral body. The operating table is adjusted until the vertebral body endplates are clearly outlined in the anterior-posterior and lateral views on fluoroscopy.

Once the skin incision is localized over the T12 vertebral body, sterile surgery drapes are placed in wide fashion around the operative field. The skin is scrubbed with betadine solution for five minutes, then "painted" with alcohol and allowed to dry spontaneously.

The skin incision site is remarked with a sterile skin marker after the alcohol has dried completely. The surgical area is finally prepped with an iodine and alcohol solution (DuraPrep™, 3M™). Sterile towels are used to border the sterile surgical field followed by a sterile antimicrobial impregnated sterile film (Ioban™, 3M™).

The remaining surgical field is isolated with sterile drapes in standard fashion. With lateral fluoroscopy, a K-wire is used to outline the middle of the surgical lesion at the T12 vertebral body and marked with a skin marker (Fig. **3a**). T12 is localized by counting vertebral bodies with "live" fluoroscopy in the lateral position from the sacrum up to T12 and is confirmed with anterior-posterior fluoroscopy.

CHAPTER 26

Second-Generation Total En Bloc Spondylectony (Second-generation TES)

Kazuya Shinmura*, Hideki Murakami, Hiroyuki Tsuchiya

Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kanazawa University, Ishikawa, Japan

Keywords: Cryoimmunology, Liquid nitrogen, Spinal tumor video, Total en bloc spondylectomy .

GENERAL ASPECTS

In the past, the following pathologies were candidates for TES: primary malignant tumor (stages I and II) [1], aggressive benign tumor (stage 3) [1] (Table **1**), and isolated metastasis with long life expectancy [2 - 4].

Table 1. Surgical strategy for primary spinal tumors [2].

<table>
<tr><td>Surgical
Staging</td><td>Cintaminatior/
Residual tumor</td><td>Surgical
margin</td><td>Spinal cord
Salvage surgery</td></tr>
<tr><td>Benign tumor:</td><td></td><td></td><td></td></tr>
<tr><td>1. Latent</td><td></td><td></td><td>Don't touch!</td></tr>
<tr><td>2. Active</td><td>OK/OK</td><td>intralesional</td><td>Debulking (piecemeal)</td></tr>
<tr><td>3. Aggressive</td><td>OK/No</td><td>intralesional or marginal</td><td>Thorough excision
(piecemeal/en bloc</td></tr>
<tr><td>Malignant tumor:</td><td></td><td></td><td></td></tr>
<tr><td>I. Low grade</td><td rowspan="3">No / No
No / No
No / No</td><td rowspan="3">marginal or wide
(radical: impractical)</td><td rowspan="3">Total en bloc excision</td></tr>
<tr><td>II. High grade</td></tr>
<tr><td>III. With metastases</td></tr>
</table>

* **Address correspondence to Kazuya Shinmura:** Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kanazawa University, Ishikawa, Japan; E-mail: kazuyashinmura@yahoo.co.jp

Federico Landriel and Eduardo Vecchi (Eds)

Now, we recommend that the indication for TES be extended, especially for malignant spinal tumor (primary malignant tumor and metastatic spinal tumor). In second-generation TES, the resected lamina and vertebral body are frozen in liquid nitrogen and used as grafted bone for spinal reconstruction, instead of harvesting autograft from the ilium or fibula (Fig. **1**). The introduction of the bone activates the tumor-specific immune response. Therefore, second-generation TES provides not only a local radical cure, but also a systemic immunological enhancement [5, 6].

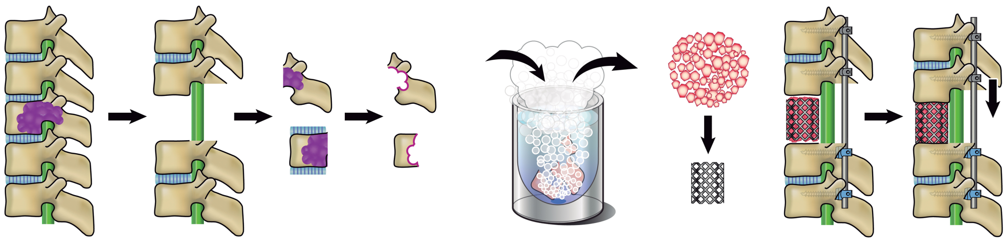

Fig. (1). Schema of second-generation TES using tumor-bearing frozen autograft [4].

SURGICAL TECHNIQUE

Preoperative Planning

The feeding artery and all segmental arteries, beginning 1 level above and extending to 1 below (a total of 3 levels) the targeted vertebra, should be embolized within 72 hours before operation [2, 3]. Embolization reduces intraoperative bleeding without compromising spinal cord function [7 - 11].

Approach

The surgical approach used depends on the spinal level affected and/or the degree of tumor development.

A. Single Posterior Approach

The single posterior approach is most commonly used in clinical practice. We usually use a single posterior approach when the affected spinal level is above L4, except when the affected level is L2 and/or the tumor involves major vessels.

B. Anteroposterior Double Approach

An anterior dissection followed by posterior TES is indicated in spinal tumor at the level of L2 and/or involvement of major vessels. When the affected level is L2, the crus of diaphragm should be dissected by the anterior approach.

C. Posteroanterior Double Approach

Posterior laminectomy and stabilization, followed by anterior *en bloc* corpectomy and reconstruction, are indicated in spinal tumors at the level of L4 or L5.

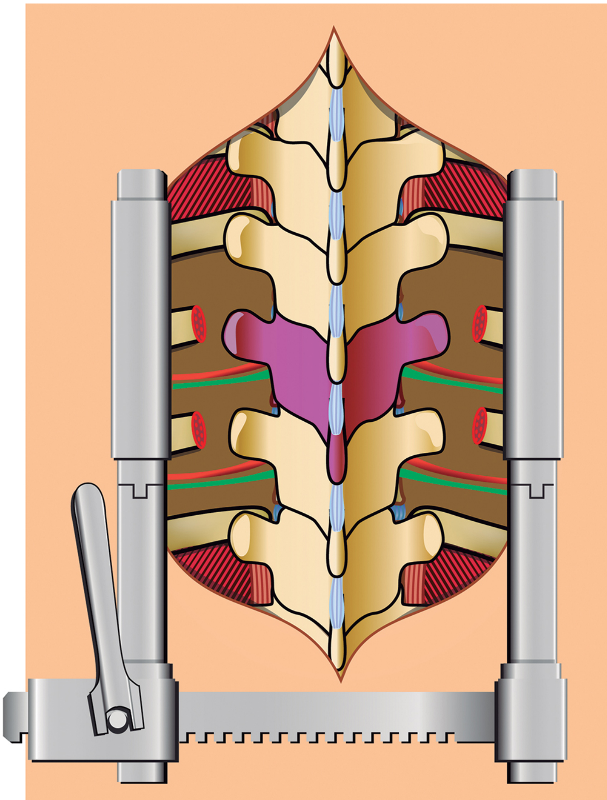

Fig. (2). Exposure: The operative field must be wide enough on both sides to dissect the ribs at the affected level and at 1 level below it.

Position and Incision

The patient is placed prone over a 4-poster frame to avoid compression of the vena cava.

CHAPTER 27

Smith-Petersen and Pedicle Subtaction Osteotomies for Spinal Deformity Correction

Mina G. Safain*, Ron I. Riesenburger, Steven W. Hwang

Department of Neurosurgery, Tufts Medical Center and Tufts University School of Medicine, Boston, Massachusetts, USA

Keywords: Pedicle subtraction osteotomy, Ponte osteotomy video, PSO osteotomy video, Smith Petersen osteotomy.

GENERAL ASPECTS

Spinal deformity correction aims to restore the spinal column sagittal, coronal, and axial alignment through surgical techniques. The specific types of osteotomy or releases required to optimally address the spinal deformity are dependent on the type of deformity, location within the spine, rigidity of the deformity, the magnitude of correction desired, and clinical factors such as bone density, prior surgery, and clinical goals. The major osteotomies used in spinal deformity correction include variations of facet osteotomies (Smith-Petersen osteotomies (SPO) or Ponte osteotomies), pedicle subtraction osteotomies (PSO), and vertebral column resections [1]. Smith-Petersen *et al.* first described their technique of posterior element removal to correct fixed sagittal deformities in rheumatoid arthritis patients in 1945, and Ponte *et al.* in 1984 described a similar technique for the correction of Scheuermann's kyphosis [2,3]. Since then, multiple variations of the technique including the development of the PSO have been emerged [4]. These osteotomies rely on shortening the posterior column in order to provide sagittal plane correction. Asymmetric shortening of the posterior elements from the right or the left side of the spine can also aid in coronal plane correction or release the spine to allow for greater axial correction. Use of both these types of osteotomies can allow for correction of spinal deformity safely.

* **Address correspondence to Mina G. Safain:** Department of Neurosurgery, Tufts Medical Center and Tufts University School of Medicine, Boston, Massachusetts, USA; E-mail: msafain@tuftsmedicalcenter.org

Federico Landriel and Eduardo Vecchi (Eds)

INDICATIONS AND CONTRAINDICATIONS

Both these types of osteotomies are used for the restoration of mainly sagittal balance in spinal deformity, although variations of these techniques can aid in coronal imbalance correction and facilitate axial improvement. Positive sagittal balance is measured by a C7 plumb line that falls anterior to the superior posterior sacral body on standing or upright 36” plain radiographs. Osteotomies are generally indicated in a rigid deformity that cannot be solely corrected with instrumentation. The major difference in these two types of osteotomies is the degree of correction per level accomplished when performing the specific osteotomy and when columns of the spine are altered. Although this chapter does not focus on this topic, it should be noted that vertebral column resection provides the greatest release and correction. An SPO shortens the posterior column, while a PSO shortens the posterior column, middle column, and some of the anterior column, thereby shortening the spinal canal [5]. A SPO is estimated to allow for approximately 5-10° of correction per level [1, 6] whereas the more substantial PSO can provide 20-30° of correction per level [1]. PSO, however, is accompanied by a higher rate of complications due to the increasing need of bony removal with studies reporting higher blood loss when compared to SPO [1].

Contraindications to this procedure include an abnormal lordosis since both these osteotomies would accentuate this. In addition, relative contraindications occur with patients with severe anterior compression that is untreated prior to closing the osteotomy as exacerbating spinal stenosis and cord or cauda equina compression may occur. Other relative contraindications to these procedures include severe osteoporosis, thereby precluding good screw purchase and ability to close the osteotomy or inability for good pedicle screw placement due to small anatomical pedicles. In addition, patients with vertebra plana at the level of the osteotomy might not achieve substantial correction with these osteotomies as the amount of bone removal is limited. Similarly, collapsed discs or the presence of autofusion of the anterior and middle columns will limit any sagittal correction through an SPO. Furthermore, these procedures are major operations and patients who have severe co-morbidities or are advanced in age should be evaluated in detail for the appropriateness to undergo these corrective procedures.

SURGICAL TECHNIQUE

Both these types of osteotomies should be accomplished with the aid of intraoperative neuromonitoring (IOM) as the placement of pedicle screws as well as the bone work and closure of these osteotomies are associated with risk of neurologic injuries. Additionally, a more significant in the PSO is to closely monitor blood loss encountered during the procedure and transfuse liberally. More frequently, surgeons are employing autologous blood recycling techniques for auto-transfusion during surgery to limit the need for transfusion. In addition, aminocaproic acid is gaining popularity in use during large spinal surgeries including surgeries involving both SPO and PSO to reduce blood loss [7]. The specific technique for performing each osteotomy is detailed below.

Smith-Petersen/Ponte Osteotomy

After standard posterior exposure of the spine is made and pedicle screws are placed, the level for the SPO is examined (Fig. **1**). The inferior articular process (IAP) is then removed. This can be achieved by using an osteotome or a drill. If an osteotome is used, it should be oriented parallel with the lamina aiming superiorly at first and then laterally to avoid injury to the neural elements (Fig. **1**). A second cut is made perpendicular to the first just below the level of the transverse process aiming slightly laterally to minimize neural injury and the inferior articulating process can then be removed. The remaining lamina can then be removed using a drill or Leksell rongeur. There is a midline raphe in the ligamentum flavum where epidural fat can be visualized. A microcurette can be used to develop the epidural plane ventral to the ligament and a Kerrison punch can be used to remove the ligamentum flavum. The superior articular process (SAP) of the caudal vertebrae is then removed with a Kerrison punch or the drill at the most rostral portion of the SAP with reference to the pedicle. This is completed bilaterally. Care is paid to the exiting nerve roots to make sure that when the osteotomy is closed there will be no neural impingement. This usually requires evaluating and removing any additional SAP laterally. The SPO is closed by either extending the patients chest by operating table or manual movement, extending the patient's hips, and/or compressing along adjacent segment pedicle screws. If additional bone removal is needed from either the caudal or rostral

CHAPTER 28

Direct Vertebral Body Derotation

Steven W. Hwang[1,*], Mina G. Safain[1], Amer F. Samdani[2]

[1] *Department of Neurosurgery, Tufts Medical Center and Tufts University School of Medicine, Boston, Massachusetts, USA*

[2] *Shriners Hospitals for Children, Philadelphia, USA*

Keywords: Axial deformity correction, DVBD video, Direct vertebral body derotation.

GENERAL ASPECTS

During deformity surgery, the primary goals are to correct the abnormal curvature while restoring balance and avoid progression of the scoliosis. However, cosmetic improvement is also an important endpoint as the rib prominence associated with scoliosis can be disfiguring. Prior surgical techniques often addressed coronal and sagittal parameters, but did not improve axial deformity and thus often required the addition of thoracoplasties to achieve satisfactory cosmetic outcomes. Direct vertebral body derotation (DVBD) allows for correction of axial deformity and cosmesis, thus improving the rib prominence. DVBD was first described by Professor Suk in 2005 [1] and has gained significant popularity in treating adolescent idiopathic scoliosis recently leading to the decrease in the use of thoracoplasty.

INDICATIONS AND CONTRAINDICATIONS

Most commonly, DVBD is used in cases of adolescent idiopathic scoliosis, but could be used for most pediatric scoliosis surgery where good screw purchase is present with a pronounced rib prominence and significant axial deformity/rotation is also present.

* **Address correspondence to Steven W. Hwang:** Department of Neurosurgery, Tufts Medical Center and Tufts University School of Medicine, Boston, Massachusetts; E-mail: shwang@tuftsmedicalcenter.org

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DVBD has not been described in the correction of adult deformity, as adult deformity is often more rigid and the presence of osteoporosis would be a relative contraindication. Poor screw purchase from the size of the pedicles, bone quality, or technical difficulties should be relative contraindications to these maneuvers. Furthermore, cases where the cosmetic outcome is not a priority or little rotation/axial deformity exists, DVBD should be reconsidered.

SURGICAL TECHNIQUE (TECHNIQUE PREVIOUSLY DESCRIBED IN [2])

Segmental

After a standard subperiosteal exposure of the desired levels and insertion of pedicle screws, a rod is placed on the concavity. Reduction techniques such us rod derotation or translation can be applied for correction. However, one should be cognizant that the rod derotation maneuver may increase the apical rotation and rib prominence; therefore adjuvant DVBD with or without thoracoplasty may be warranted. Although we prefer performing DVBD across the concave rod, the same technique can be applied with both rods or across the convexity.

Both neutral vertebra rostral and caudal to the instrumented levels should be identified and secured with derotation devices to act as a counterforce to the rotatory correction (Fig. **1A**). The surgeon may start rostrally or caudally and gradually march towards the other end of instrumentation. The neutral vertebra set screws are then tightened and the remaining intervening set-screws loosened. Derotation devices, or derotation tubes, can then be attached to the adjacent level and corrective rotatory axial force applied (Fig. **1B**). A downward and medializing force should be applied to the convex derotation device while an upward, pulling force is applied to the concave derotation device. Simultaneously, counterforce in the opposing rotational direction should be applied to the neutral vertebra and additional downward force should be distributed across the rib prominence (Fig. **1B**). The set screw should be tightened aggressively. This step should be repeated across all levels until the neutral vertebra at the other extent of the instrumentation is reached.

Segmental Technique

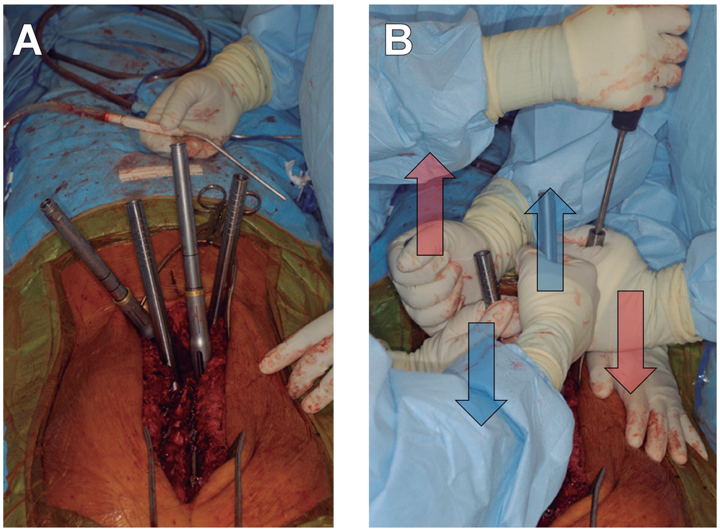

Fig. (1). A) Intraoperative picture displaying the attachment of the derotation tubes to the neutral vertebra and target level. B) Intraoperative image showing derotational forces being applied as described.

Hypothetically, segmental derotation may allow for application of more significant force to individual vertebra, although excessive force may lead to screw break-out and weakening of screw purchase.

En-bloc Derotation

The initial exposure and rod reduction techniques are identical to that described for segmental derotation. The neutral vertebrae are identified and derotation devices are similarly attached. Derotation devices are then attached to all screws in between. The entire block segment between the upper and lower neutral vertebrae can be connected to move "en-bloc" by first connecting the derotation devices on each side through a locking device (extending 2-3 levels with bilateral fixation). The two parallel "locking devices" can then be connected *via* a "cross-link" (Fig. **2**). The neutral set-screws should be tightened and the intervening ones should then be loosened. A handle can then be attached to the construct and the entire bloc can be rotated simultaneously. Application of concurrent counterforce should be applied to the rostral and caudal neutral vertebrae as well as a strong, evenly-distributed downward force across the rib prominence. The remaining set-

CHAPTER 29

Rod Cantilever Constructs and Techniques

Yiping Li*, **Daniel K. Resnick**

Department of Neurological Surgery, University of Wisconsin Medical School, Madison, WI, USA

Keywords: Biomechanics, Rod cantilever, Spinal constructs, Spine instrumentation.

GENERAL ASPECTS

Spinal instrumentation was first described by Harrington based on his experiences from the early 1950s. Harrington used a combination of hooks and rods to correct deformities in scoliosis [1]. Instrumentation facilitates deformity correction through application of various forces upon the spine. Although Harrington's landmark paper suggested spinal instrumentation to be an effective mean for treating spinal instability and deformity, the biomechanical forces behind his techniques were not well understood until decades later.

Giovanni Borelli is considered by some to be the founding father of spine biomechanics because of his descriptions from the 1700s; however, modern understandings of spinal biomechanics were popularized by Francis Denis. In his 1983 paper, Denis described the three-column model for spinal fractures [2]. These theories sparked interest in spinal biomechanics and have led to more sophisticated and refined treatment modalities.

Rod cantilever techniques utilize the principles of spine biomechanics to treat a broad range of spinal pathology. These systems can be used for degenerative, traumatic, infectious, congenital, or neoplastic causes of spinal destabilization. The theory behind using rod cantilevers in spine surgery is to provide stability over a spinal pathology through load sharing and force dispersion thus facilitating recovery and preventing further injury [3].

* **Address correspondence to Yiping Li:** Department of Neurological Surgery, University of Wisconsin Medical School, Madison, WI, USA; E-mail: YLi2@uwhealth.org

Federico Landriel and Eduardo Vecchi (Eds)

Although a technically more demanding procedure, rod cantilever constructs provide a more rigid fixation of the spinal elements compared to wire and hook constructs. Higher nonunion rates and longer postoperative immobilization times have traditionally been associated with wiring and hook constructs because of residual spine mobility [4 - 6].

Advantages of using rod cantilever techniques over hook and wire constructs include improved deformity correction, greater immobilization, shortened construct strength, enhanced fusion rates, and an alternative approach when other techniques are contraindicated [7 - 11]. Rod Cantilever techniques are ideally suited for high stress correction deformity in the setting of trauma or deformity surgery [3].

TYPES OF CANTILEVER SYSTEM AND INDICATIONS

A cantilever is any rigid projecting structure that provides support at one end while being fixed at the other. These structures can be beams, rods, screws, or any combination that forms a structural framework and is used to carry a load. In spine surgery, this load refers to forces applied to screws that are rigidly fixed to a longitudinal rod or plate.

Cantilever fixation systems are typically broken down into three types: fixed moment, non-fixed moment, and applied moment arms. Each of these types presents a different biomechanical advantage and drawback - the indications for each modality depend on the pathology as well as patient comorbidities [3].

A fixed moment arm construct consists of screws rigidly fixated to longitudinal rods or plates which results in a fixation system that resists axial loading forces. An illustrative case for use of fixed moment constructs would be utilizing pedicle screws to stabilize the lumbar spine after a laminectomy and decompression at the L5/S1 level for spinal stenosis and spondylolisthesis. The pedicle screws are rigidly connected to longitudinal rests facilitating load transmission down the construct. This rigid construct prevents further listhesis, thus preventing spinal column instability and improving bony fusion [3, 12].

Non fixed moment arm techniques are similar to fixed moment arm systems;

however, biomechanically they lack an immobile longitudinal connection, which leads to ineffective load bearing transmission by the construct. Non fixed moment arms do not effectively support axial loading forces and necessitate additional support systems, such as additional instrumentation or grafts for load sharing and resistance to translation along a spinal pathology [3, 12].

Indications for non fixed moment arm techniques include patients with intact posterior spinal elements or grafts to help with axial load sharing. An illustrative case would be using anterior screws, plates, ventral bone graft, and a cage system to stabilize the spine after an anterior cervical discectomy and corpectomy. In these cases, ineffective axial load transmission from the use of a non-fixed moment arm construct results in load sharing with the anterior graft. The axial compressive forces on the ventral bone graft promotes bony fusion and reduces pseudarthrosis [3, 12 - 14].

Applied moment arm techniques involve the use of a fixed moment arm to apply a distractive, compressive, or rotational force upon the spine. The most common clinical indication for applied moment arms are for spinal deformity correction. Various forces are applied after assembly of the construct to maintain spinal reduction.

An illustrative case would be stabilization of the spinal elements using pedicle screws with a fixed moment arm construct after pedicle subtraction osteotomy in the lumbar spine. Immobilization in extension exerts a continuous compressive force upon the posterior elements of the lumbar vertebrae and facilitates fusion and deformity correction for sagittal balance correction [3, 12].

SURGICAL TECHNIQUE

Approaches aimed at preventing the incidence of instrument failure are based on the biomechanical principles of load sharing, implant purchase, and instrument stress resistance. Optimizing these factors prevents excessive forces acting upon a particular location along the cantilever construct. Instrumentation strength is dependent on the material properties but for all intents and purposes constructs with greater screw/rod diameter or plate thickness have a greater ability to resist bending moments [17 - 19].

CHAPTER 30

Experiences of Vertical Expandable Prosthetic Titanium Rib (VEPTR)

Zezhang Zhu*, **Yong Qiu**

Department of Spine Surgery, Drum Tower Hospital, Nanjing University Medical School, Jiangsu, China

Keywords: Expandable rib prosthetic, Scoliosis surgery, VEPTR surgical technique, VEPTR video.

GENERAL ASPECTS

The VEPTR device is a metal rod curved to fit the spine and is placed in an up and down position. It can be made longer as your child grows. This helps the spine become straighter and allows the lungs to grow and to fill with enough air to breathe. The device is made of titanium because of its strength and ability to stay inside the child without causing a bad reaction. The purpose of VEPTR included: 1. Increase thoracic volume; 2. Scoliosis correction; 3. Thoracic symmetry by lengthening the concave, restricted hemithorax; 4. Improve thoracic function; 5. Avoid growth inhibition procedures; 6. Maintain these improvements throughout the child`s growth [1, 2].

INDICATIONS AND CONTRAINDICATIONS

Indications for the application of Vertical Expandable Prosthetic Titanium Rib (VEPTR) are listed as the following:

- Primary Thoracic Insufficiency Syndrome (TIS) due to three dimensional deformity of the thorax
- Progressive thoracic congenital scoliosis with concave fused ribs

* **Address correspondence to Zezhang Zhu:** Department of Spine Surgery, Drum Tower Hospital, Nanjing University Medical School, Jiangsu, China; E-mail: zhuzezhang@gmail.com

Federico Landriel and Eduardo Vecchi (Eds)

- Progressive thoracic congenital scoliosis with flail chest due to absence of ribs
- Progressive thoracic congenital, neurogenic or idiopathic scoliosis without rib abnormality
- Hypoplastic thorax syndromes
- Jeune's Syndrome
- Jarcho-Levine Syndrome
- Cerebro costal mandibular syndrome
- Other, including congenital chest wall defect, acquired chest wall defect, chest wall tumor resection, traumatic flail chest.

Contraindications for the application of Vertical Expandable Prosthetic Titanium Rib (VEPTR) are listed as the following:

- Inadequate strength of bone (ribs/spine) for attachment of the VEPTR
- Absence of proximal and distal ribs for attachment of the VEPTR
- Absent diaphragmatic function
- Inadequate soft tissue for coverage of the VEPTR
- Age beyond skeletal maturity for use of the VEPTR
- Age below 6 months
- Known allergy to any of the device materials
- Infection at the operative site

In addition, some extra points need to be taken into account before using VEPTR. It should be noted that patients implanted with VEPTR should not be braced. The VEPTR device is designed to allow for thoracic cavity growth and the restrictive nature of a brace would not help the condition, but defeat its purpose. Besides, patients may require additional wound protection to prevent inadvertent rubbing or bumping of the wound [3 - 5].

SURGICAL TECHNIQUE

Patient Positioning

Place the patient in a lateral decubitus position similar to that required for a standard thoracotomy. To protect against brachial plexus injury, do not flex the shoulder more than 90°.

Cranial Exposure

Make a J-shaped thoracotomy incision without disrupting the periosteum overlying the ribs. Retract the skin flaps. Continue the incision and elevate the paraspinal muscles medially only to the tips of the transverse processes. Gently elevate the scapula to expose the middle and posterior scalene muscle.

Insertion Cranial Implants

1. Identify Cranial Rib

Identify the cranial rib to be used as the cranial point of attachment. Mark this point and confirm location using radiographic imaging. Because of the risk of brachial plexus impingement, do not choose the first rib as the cranial point of attachment.

2. Prepare Rib for Implants

Make a 1 cm incision into the intercostal muscles above and below the rib where the Cranial Rib Support will attach. Insert the Periosteal Elevator with slightly curved blade or the curved Periosteal Elevator to carefully elevate the periosteum adjacent to the lung. Take care to preserve the soft tissue surrounding the rib to protect rib vascularity and the neurovascular bundle.

3. Select Proper Cranial Rib Support

Choose a 220 mm or 70 mm radius Cranial Rib Support and use the Rib Support Feeler to prepare the rib for the Cranial Rib Support and the Closing Half-Ring. Use the Holding Forceps for Rib Support.

4. Seat Cranial Rib Support

Seat the underside of the Cranial Rib Support into the space between the periosteum and the rib. Rotate the rib support into the correct position. For the medial construct, seat as medial as possible to the transverse process.

CHAPTER 31

Robotic Thoracic Surgery

Evan M. Begun*, Jorge Mendoza-Torres, Mick Perez-Cruet

Michigan Head and Spine Institute, William Beaumont Hospital, Royal Oak, Oakland University, Michigan, USA

Keywords: Da vinci, Minimally invasive, Robotic surgery video.

INDICATIONS AND CONTRAINDICATIONS

The da Vinci robotic surgical system has been in use since its FDA approval in 2000, and was initially approved for use in general, urologic, and gynecologic laparoscopic procedures [1]. During this time period, the da Vinci system has also been indicated for thoracic surgeries of the lungs, mediastinum, and esophagus. These include lung resection, parathyroid gland resection, and thymectomy amongst others [2]. Furthermore, we have described the use of da Vinci system Fig. (**1**) in combination with minimally invasive (MIS) posterior approach Fig. (**2**) for the resection of complex paraspinal schwannomas with thoracic extension [3]. Minimally invasive robotic surgery has also been shown to provide patients with better outcomes and fewer complications, as well as a cost-effective alternative to traditional open procedures [4].

A lack of long-term outcomes and quality of life data for da Vinci robotic procedure precludes a meaningful comparison with open approaches. Thus, few pure contraindications to using the da Vinci system have been defined. However, the use of da Vinci system requires specialized surgeon training which has a steep learning curve. It is vital for surgeons to be familiar with rapidly evolving robotic surgical techniques in order to properly utilize the da Vinci surgical system.

* **Address correspondence to Evan M. Begun:** Michigan Head and Spine Institute, William Beaumont Hospital, Royal Oak, Oakland University, Michigan, USA; E-mail: evan.begun@gmail.com

Federico Landriel and Eduardo Vecchi (Eds)

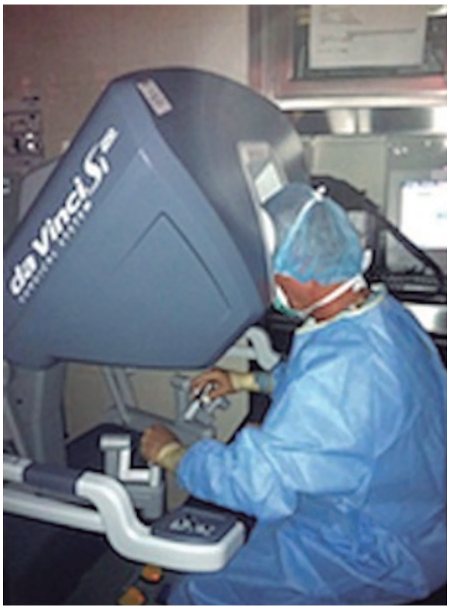

Fig. (1). A Physician Sitting at The Da Vinci Control Console.

SURGICAL TECHNIQUE

For the previously described resection of a complex, T2-3 paraspinal schwannoma with thoracic extension, the technique is as follows. The patient was initially placed prone Fig. **(2)** on a radiolucent Jackson table (Mizuho OSI, Union City, California), and the tumor level was determined with anteroposterior thoracic chest x-ray. The tumor extended from T2-3, expanding the neural foramina, with erosion of the T3 vertebrae. A 2-cm incision was made 3 cm lateral to the midline, and serial muscle dilation was performed to allow docking of the MIS tubular retractor system with the T2-3 facet. Some tissue was removed to expose the facet complex and ipsilateral lamina. Laminectomy and facetectomy were performed to expose the intraspinal portion of the tumor (Fig. **3**). The tumor sheath was cut, and the tumor was debulked in a piecemeal fashion. Duragen (Integra LifeSciences, Plainsboro, New Jersey) and Tisseel (Baxter, Deerfield, Illinois) were placed over the dura to prevent cerebrospinal fluid leak into the thoracic cavity. Morselized autologous bone collected during the procedure with the BoneBac Press((Thompson-MIS, Traverse City, Michigan) was used for posterolateral arthrodesis at the T2-3 level. The retractor was removed, and the incision was closed.

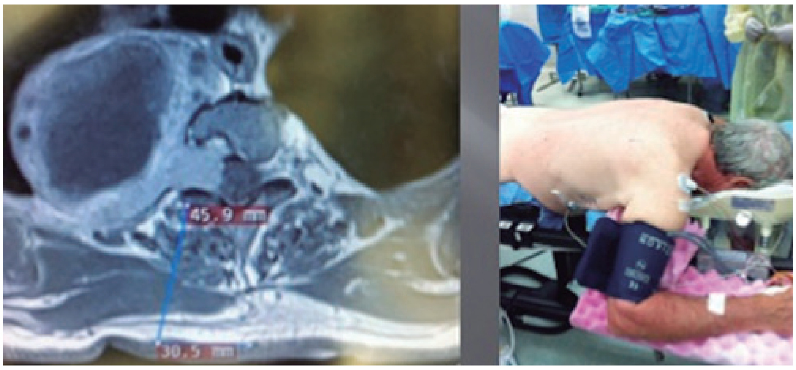

Fig. (2). Showing a Patient Positioned on Table For Minimally Invasive Approach.

The patient was then placed into the supine position and underwent minimally invasive thoracoscopy using the da Vinci robotic surgical system. The intrathoracic portion of the tumor was visualized, removed from its adhesions, and resected *en bloc* from the thoracic cavity. Gross total resection of the tumor was achieved. Combined estimated blood loss was about 250 ml.

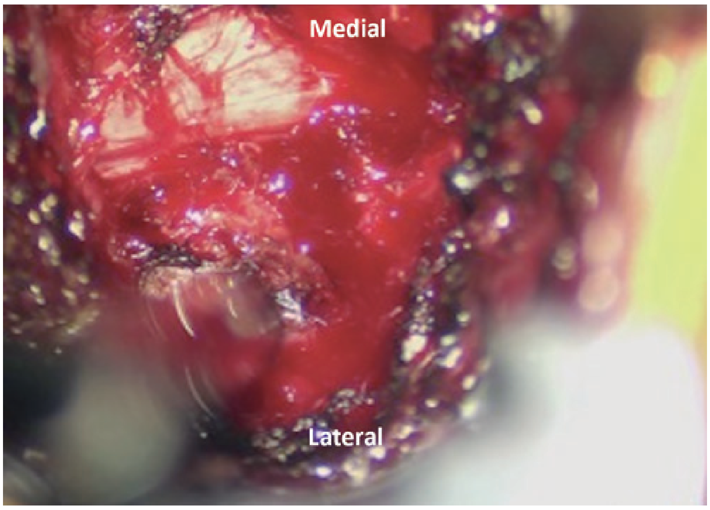

Fig. (3). Intraoperative Picture showing an Intraspinal Portion of The Tumor.

COMPLICATIONS

The patient experienced no intraoperative or postoperative complications.

SECTION III - SACROLUMBAR SPINE

CHAPTER 32

Lumbar Foraminotomy

Abdul Karim Msaddi*

Neurosurgical and Spinal Department, Neuro Spinal Hospital, Dubai, UAE

Keywords: Discectomy technique, Discectomy video, Foraminotomy, Microdiscectomy.

GENERAL ASPECTS

The aim of the lumbar foraminotomy is to decompress the nerve root, which is compressed in general by either one or more of the following elements:

- Osteophytes overgrowth of the superior articular process of the facet joint
- Hypertrophy and infolding of the ligamentum flavum
- Foraminal disc herniation
- Posterior vertebral bodies spur-osteophytes affecting the anterior part of the foramen

Pure foraminal disc herniations, encountered between the medial and lateral borders of the pedicle, are rare; they represent the 3% of all disc herniations [1]. Usually foraminal herniations are part of paracentral and foraminal or foraminal and extraforaminal disc herniations.

The clinical picture is presented mainly by radiculopathy resistant to conservative treatment in full concordance with a clear MRI or even better with MRI myelography images [2] with or without CT scan for better visualization of bony elements.

Hasegawa estimated that a foramen is stenotic when the height is less than 15 mm and the width is less than 4 mm, and it seems to be associated with nerve compression in 80% of the time [3].

* **Address correspondence to Abdul Karim Msaddi:** Neurosurgical and Spinal Department, Neuro Spinal Hospital, Dubai, UAE; E-mail: nsshmeet@yahoo.com

Federico Landriel and Eduardo Vecchi (Eds)

INDICATIONS

Elective surgery is the rule; it is not an emergency, the patient needs to be fit for general anesthesia although it can be done under local anesthesia with possible need for intravenous sedation. Failure to diagnose correctly the level of nerve root compression between the foramen or in the lateral recess or in both together represents a common cause of failed back surgery [4]. Jenis LG, *et al.* showed that a missing foraminal stenosis represent a frequent cause of persisting symptoms after surgery [5].

MAIN PATHOLOGIES

- Foraminal stenosis associated with central stenosis: in which case the decompression needs to be extended after foraminotomy to the central canal, due mainly to ligamentum flavum hypertrophy frequently associated to disc bulge.
- Foraminal disc herniation.
- Lateral recess stenosis due to hypertrophy of superior articular process (SAP) causing additional foraminal stenosis.
- Grade I-II spondylolisthesis causing foraminal stenosis with no documented instability on dynamic imaging.
- Degenerative disc disease with decreased disc height associated to posterior osteophytes of vertebral body causing symptomatic foraminal stenosis.
- Combination of more than one of the mentioned pathologies.

CONTRAINDICATIONS

- General: bleeding problems, active infection, critical general conditions contraindicating general anesthesia
- Local: far lateral extraforaminal disc herniation
- Grade I or II spondylolisthesis with instability
- Spondylolisthesis grades III and IV

SURGICAL TECHNIQUE

General anesthesia. The patient is placed in prone position on Wilson frame if there is no planning for fusion or instrumentation. The index level is marked under fluoroscopy in lateral view using a spinal needle inserted in the opposite side to the pathology. A 2-3 cm midline skin incision or 0.5-1 cm paramedian to the side of the foraminotomy is made. The fascia is opened using monopolar cautery. Subperiosteal dissection of the muscles in the interlaminar space is performed, exposing the rostral and caudal laminae, medial part of the facet joint and the pars (Fig. **1**).

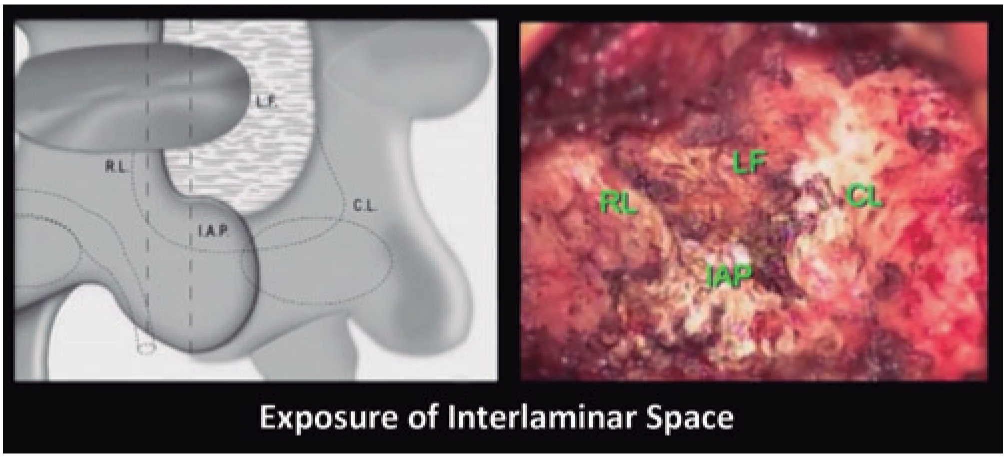

Fig. (1). R.L. Rostral Lamina, CL. Caudal Lamina, L.F. Ligamentum Flavum, IAP Inferior Articular Process.

A microdiscectomy retractor (*Williams or others*) is applied. For intramuscular approach the fascia incision is done 1 to 1.5 cm paramedian and the muscles are splitted using the finger and blunt dissectors to reach the medial part of the facet joint and the lateral part of interlaminar space. Cervical spine retractor is preferred for this approach as it offers better rostrocaudal and medio-lateral exposure.

About 6 to 8 mm of the lower part of rostral lamina is drilled out up to the insertion of the ligamentum flavum. Drilling is continued to include the medial third of the lower facet until the joint surface. Then the medial part of superior articular process (SAP) from the caudal vertebra is exposed and drilled out (Fig. **2**). This will provide, after ligamentum flavum removal, a sufficient exposure of the disc space more lateral and will enlarge the proximal foramina, allowing for more exposure and decompression of the exiting nerve root.

If the lower lateral recess is part of the stenotic syndrome, we extend the removal of the SAP from medial aspect of the pedicle to its lower aspect. After thinning

CHAPTER 33

Minimally Invasive Endoscopic Bilateral Decompression through a Unilateral Approach for Lumbar Stenosis

Samer G. Zammar*, **Albert P. Wong, Nader S. Dahdaleh, Richard G. Fessler**

Department of Neurosurgery, Rush University Medical Center, Chicago, Illinois, USA

Keywords: Endoscopic, Laminectomy, Lumbar stenosis video, Minimally invasive.

CASE PRESENTATION

40 year-old right handed male with a history of low back pain and bilateral leg pain with ambulation. He describes difficulty walking more than 100 feet but the pain resolves with rest and forward flexion at the waist. He is able to ambulate farther when he uses a walker or is leaning on a shopping cart. He denies any weakness in his extremities, or difficulties in control of bladder or bowels. He has tried medical management without improvement in his symptoms. On physical exam, the patient is strong throughout without sensory deficits. His reflexes are 2+ in the bilateral lower extremities. There is no clonus, Babinski's sign or Hoffman's sign on examination. He has clinical symptoms and signs of neurogenic claudication.

IMAGING STUDIES

An MRI of the lumbar spine without contrast demonstrates a moderate canal stenosis at L4-5. There is hypertrophy of the facets and ligamentum flavum, as well as degenerative disc disease combining to form spinal stenosis (Fig. **1**).

* **Address correspondence to Samer G. Zammar:** Department of Neurosurgery, Rush University Medical Center, Chicago, Illinois, USA; E-mail: samer.zammar@northwestern.edu

Federico Landriel and Eduardo Vecchi (Eds)

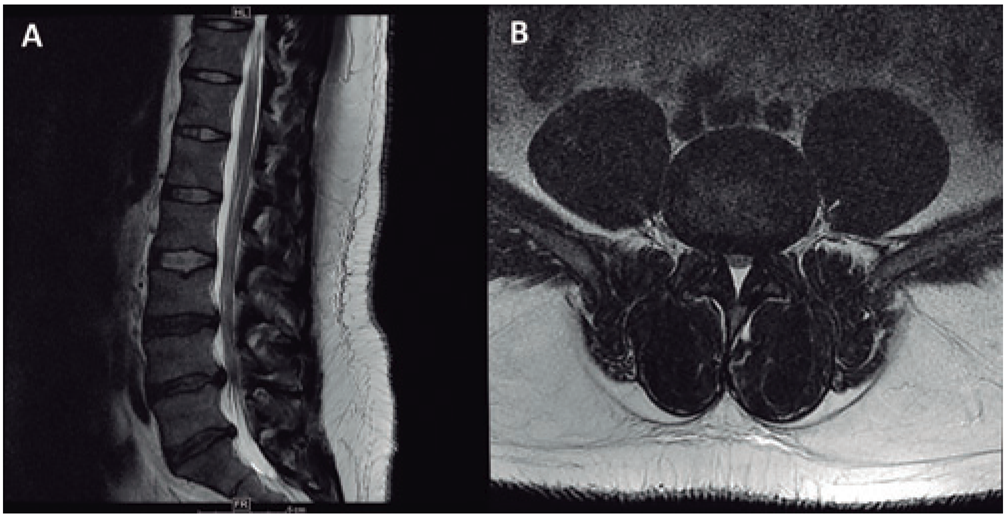

Fig. (1). MRI of The Lumbar Spine Demonstrates Moderate Spinal Stenosis From Hypertrophy of The Facets And Ligamentum Flavum, as Well as Degenerative Disc Disease.

SURGICAL TECHNIQUE

Positioning

The patient is turned prone onto a radiolucent operating table on top of a Wilson frame with the arms placed cephalad, away from the surgical site. All bony prominences and vulnerable pressure points are padded. The skin is shaved and cleaned with alcohol. The midline is marked with a skin marker over the prominent spinous processes and a parallel skin incision is drawn 1.5cm ipsilateral (left) of the midline. Once the skin incision is localized over the L4-5 level, sterile surgery drapes are placed in wide fashion around the operative field. The skin is scrubbed with betadine solution for five minutes, then “painted” with alcohol and allowed to dry spontaneously. The skin incision site is remarked with a sterile skin marker after the alcohol has dried completely. The surgical area is finally prepped with an iodine and alcohol solution (DuraPrep™, 3M™). Sterile towels are used to border the sterile surgical field followed by a sterile antimicrobial impregnated sterile film (Ioban™, 3M™). The remaining surgical field is isolated with sterile drapes in standard fashion.

Intraoperative Neurophysiologic Monitoring

Somatosensory evoked potentials and motor evoked potentials are placed during general anesthesia prior to final positioning of the patient.

Incision

The original skin incision was marked and localized with fluoroscopy fifteen millimeters ipsilateral to the midline. The incision is infiltrated with a combination of 0.5% Marcaine and 1:200,000 Epinephrine solution for local anesthesia and hemostasis. The incision length is made with a #15 scalpel blade about twenty-five millimeters long.

Soft Tissue Dissection

Monopolar electrocautery is used to extend the incision deep to the subcutaneous tissue and through the fascia of the paraspinal muscles. A K-wire is placed onto the ipsilateral laminofacet junction at the surgical level and confirmed with lateral fluoroscopy. Sequential placement of serial muscular-splitting dilating tubes are placed until the final tubular retractor is secured with the flexible arm attached to the operating table. Lateral fluoroscopy is used to confirm the final retractor tube is centered over the ipsilateral laminofacet junction (left L4-L5). The remainder of the soft-tissue overlying the L4-L5 laminofacet is removed with monopolar electrocautery. The operating microscope is brought into the surgical field for the bony decompression.

Bilateral Laminectomies

An upangled curette is used to define the sublaminar plane of L4 and L5. Kerrison rongeurs #2 or #3 are used to perform the L4-L5 laminotomies and create the surgical borders toward the rostral and caudal pedicles. A combination of Kerrison rongeurs and a high-speed drill is used to resect the ipsilateral medial half of the L4-L5 facet joint. Caution should be exercised to prevent inadvertent plunging of the pneumatic drill and potential injury to the dura and spinal nerve roots below. After the bony decompression is complete, the ligamentum flavum is left in place to protect the underlying thecal sac during the contralateral decompression. The tubular retractor is then angled medial to expose the

CHAPTER 34

Transforaminal Endoscopy for Disc Herniations

Anthony T. Yeung[1,*], Satishchandra Gore[2]

[1] *Department of Neurosurgery, University of New Mexico, School of Medicine, Albuquerque, New Mexico, Desert Institute of Spine Care, Phoenix, Arizona, USA*

[2] *Orthopedics Department, Prime Surgical Center, Pune, MS, India*

Keywords: Axilla, Exiting nerve, Lateral stenosis, Local anesthesia.

GENERAL ASPECTS

In 1986 Kambin published initial work about transforaminal endoscopy [1]. The understanding and philosophy has changed with respect to indirect decompression, ablation, irrigation, desensitization, decompression and mobilization of nerves with emphasis on removing the source of the inflammatory response, which forms the basis of pain [2, 3].

In basic endoscopy, central debulking of disc was done, after confirming safe entry through the annulus. Around 1995, a conceptual change was to study of foraminal anatomy get a more clear understanding of the pain generator and produce instruments needed to decompress, ablate, and irrigate the source of pain. Study by Mirkowitz, performed by his resident David Swartz, highlighted maximum size of cannula, which we can safely put in the foramen for safe endoscopic surgery [4]. Now the endoscopic surgery has advanced, with cannula designs that can protect and retract nerves in the foramen while visualizing the disc from the foramen and intradiscally, looking for the source of the patho-anatomy; and way beyond, in an awake and aware patient. We can now treat moderate and large extruded or migrated herniations by accessing the fragment with the "inside-out" philosophy. This is because the source of the patho-anatomy namely annular tear usually originates intradiscally. It is now possible to visualize

* **Address correspondence to Anthony T. Yeung:** Department of Neurosurgery, University of New Mexico, School of Medicine, Albuquerque, New Mexico, Desert Institute of Spine Care, Phoenix, Arizona, USA; E-mail: ayeung@sciatica.com

Federico Landriel and Eduardo Vecchi (Eds)

foraminal structures and epidural space by widening the foramen (foraminoplasty) through ablation of superior facet and foraminal ligament. This can help to direct decompression of the exiting and traversing nerve roots with straight and side firing lasers, trephines Kerrisons, and burrs used to decompress the facet to gain access to the epidural space caudal and cephalad to the disc behind the vertebral body.

Fine forceps and a hook will allow easier removal of sequestered fragments. We also add thermal annuloplasty with bipolar radiofrequency to treat discogenic low back pain arising from non healing chronic posterior annular tear if needed. Now, additionally facet denervation and other applications are available for treatment of chronic back pain.

It was in 1997 that Yeung first published his concept of Selective Endoscopic Discectomy™, although Yeung has used indigocarmine dye and lasers since 1992. The evolving methodology was then was republished in 2001 [5]. This stage of advanced endoscopy was possible due to foraminoplastic approach. In 2002, Yeung and Tsou described the technique with specialized instruments able to treat all forms of disc herniation by transforaminal approach [6, 7].

While arthroscopic lumbar discectomy is a term first proposed by Parviz Kambin indigocarmine dye, through a working “triangular zone”, the evolution and expansion of Kambin’s technique since 1991 has made the term endoscopic discectomy more appropriate in describing the transforaminal approach to the disc. Selective endoscopic discectomy™ is a trademarked term by Yeung for modification and expansion of Kambin’s initial technique.

We have standardized the technique “YESS SYSTEM”. It consists of basic 6 steps described later. They essentially have crystallized learning of transforaminal endoscopy to a single important step of putting the needle precisely in the working zone in foramen, which holds the pain generators or is close to pain generators (Fig. **1**).

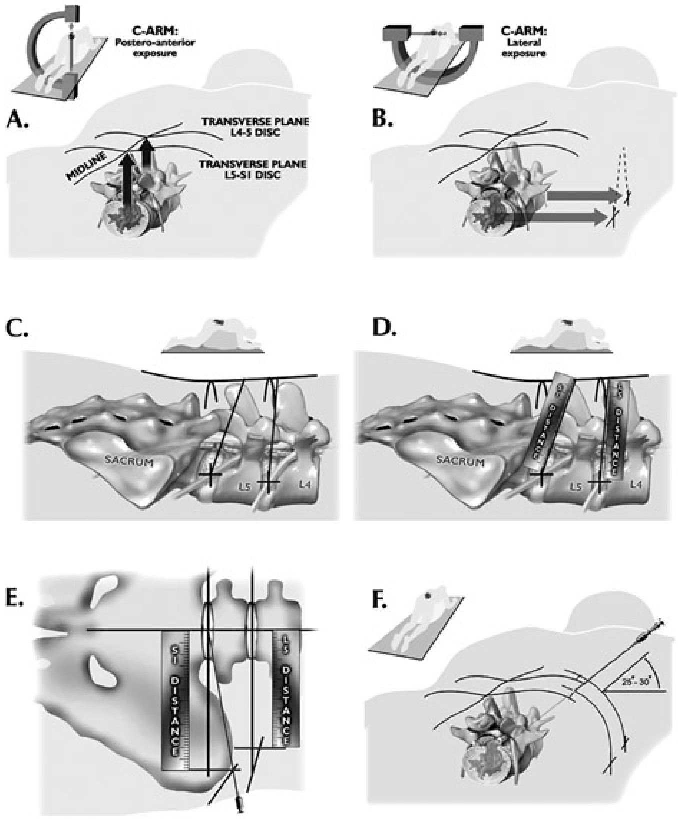

Fig. (1). The illustration shows the 6 steps crystallized concepts in transforaminal endoscopy for precision and safety.

A. Drawing lines to detect midline and disc level as is seen.
B. Mark depth of the disc.
C. Mark disc inclination and plan for entry.
D. Measuring depth and inclination. For injections we measure up to centre of disc; typically it is 8 cm for surgery the distance is measured to front of the disc, and can be about 10.5 to 11 cm. Inclination of the disc is always towards the head due to lumbar lordosis.
E. Taking same distance from midline above the original disc line makes us identify point of entry of the needle.
F. Entry was initially at an angle of 25° subfacetal in the foramen through paraspinal muscles. As techniques evolved, we started more laterally as much as 11 cm away from midline and at 20° but never at zero degrees because the

CHAPTER 35

Minimally Invasive Endoscopic Decompression of Foraminal Stenosis under Local Anesthesia

Anthony T. Yeung[1,*], Satishchandra Gore[2]

[1] *Department of Neurosurgery, University of New Mexico, School of Medicine, Albuquerque, New Mexico, Desert Institute of Spine Care, Phoenix, Arizona, USA*

[2] *Orthopedics Department, Prime Surgical Center, Pune, MS, India*

Keywords: Axilla, Exiting nerve, Local anesthesia, Percutaneous interbody fusion.

GENERAL ASPECTS

Our understanding of spinal stenosis has vastly improved over the past 150 years, when spinal stenosis resulting from disc degeneration in stenosis was described by Harris and Macnab [1]. The area underlying superior articular process was highlighted by Macnab [2]. Spinal canal stenosis symptomatology as neurogenic claudication was described by Verbiest.[3]. Lumbar spinal is narrowing of the central spinal canal stenosis, lateral recess or the neural foramen. The term indicates a pathological condition causing compression of neural and vascular structures [4].

The lumbar spinal canal shape varies, it is generally round, ovoid, triangular or trefoil. The thecal sac containing the cauda equina occupies this conduct. Central stenosis commonly develops with aging, narrowed by dorsal canal structures as the spine ages and facet and ligamentum flavum hypertrophies. It however, takes significant compression and narrowing for intermittent claudication, a classic symptom, to become debilitating. Most patients with spinal stenosis also have associated lateral stenosis, with or without a trefoil canal configuration. "The

* **Address correspondence to Anthony T. Yeung:** Department of Neurosurgery, University of New Mexico, School of Medicine, Albuquerque, New Mexico, Desert Institute of Spine Care, Phoenix, Arizona, USA; E-mail: ayeung@sciatica.com

Federico Landriel and Eduardo Vecchi (Eds)

lateral canal is the semitubular structure through which the nerve root runs from the thecal sac to the intervertebral foramen. The proximal part, also called the subarticular or intervertebral portion, is limited anteriorly by the intervertebral disc and posterolaterally by the superior articular process and the facet joint. The intervertebral disc contributes to the stenosis in the subarticular area. The distal part of the canal corresponds to the lateral recess, *i.e.*, the lateral corner of the vertebral foramen at the level of the pedicle. The entrance and exit of the intervertebral foramen lie at the medial and lateral borders of the pedicle. Bony and soft tissue hypertrophy of the inferior articular process may cause narrowing of the central portion of the spinal canal". Decompression of the protruding annulus in stenosis, that is usually collagenized or even calcified, helps.

The subarticular and lateral facet of the superior articular process (SAP) may cause partial deformation of the central portion of the central canal as well as the subarticular, and lateral portions of the canal as the nerve root exits. Hypertrophy of the lateral facet produces narrowing of the intervertebral foramen, but additional disc protrusion of any degree by the disc will also affect the nerves in the thecal sac and foramen.

Lee and Rauschning have described how progressive degenerative processes affect the dorsal root ganglion, the mini brain of the nerve, and how it is affected by the disc, facet, synovium of the facet joint, and osteophytes in the foramen (Fig. **1**).

The lateral root canal is not understood well because surgeons do not see the intricacies of the microanatomy during traditional open or even microscopically guided decompression. "Burton [6] divided the nerve root canal into three portions separated by the pedicle in the cross-sectional plane, namely central, foraminal, and extraforaminal.

This classification allows easy imaging diagnosis. Lee *et al*. [5] classified the lateral lumbar spinal canal into three zones: entrance, mid, and exit". In patients with radicular symptoms stenosis is a contributing cause from all three zones.

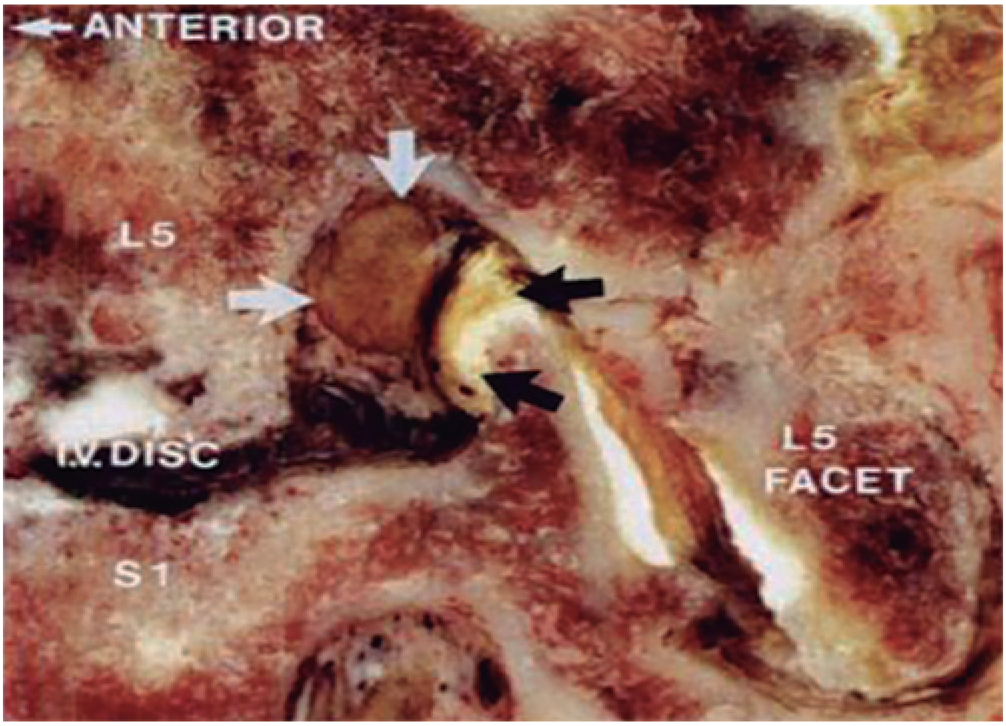

Fig. (1). Dorsal root ganglion, the mini brain of the nerve, and how it is affected by the disc, facet, synovium of the facet, and osteophytes in the foramen.

On MRI imaging, Wildermuth *et al*. [7] suggested grading lumbar spinal foraminal stenosis. It was only based on obliteration of the epidural fat, but did not consider direct nerve root compression or deformity. Lee *et al*. [8] in his new classification and grading has considered nerve root compression as a part of the criteria. Yeung and Gore described the patho-anatomy of stenosis as seen from the foramen endoscopically. The absence of fat, vascular pulsation, scarred and fibrotic nerve roots and the axilla between the traversing and exiting nerves served basis of unrecognized symptomatic stenosis in the hidden zone [9].

INDICATIONS AND CONTRAINDICATIONS

The traditional indication for intervention is severe nerve root compression, claudication with severe limitation of walking, moderate or no neurological deficit and patients with degenerative listhesis who may have additional back pain, which most of the times is absent in other patients [10].

CHAPTER 36

Foraminal and Dorsal Endoscopic Rhizotomy

Anthony T. Yeung[1,*], Satishchandra Gore[2]

[1] *Department of Neurosurgery, University of New Mexico, School of Medicine, Albuquerque, New Mexico, Desert Institute of Spine Care, Phoenix, Arizona, USA*

[2] *Orthopedics Department, Prime Surgical Center, Pune, MS, India*

Keywords: Axilla, Exiting nerve, Lateral stenosis, Local anesthesia.

GENERAL ASPECTS

Mooney and Robertson described facet syndrome in 1976. They used steroids or local anesthetic injected under fluoroscopy for diagnosis and therapy. The facet joint was found to cause persistent low back pain [1].

In 1981, Bogduk published a study of anatomy of an osseous fibrous tunnel that sometimes shielded the medial branch of the dorsal ramus that he named the lumbar mamillo-accessory ligament (MAL). The medial branch enervated the facet at and below the disc level. This keeps the medial branch in a relatively constant relationship to bone, so interventions and needle techniques to stimulate, anesthetize or ablate the medial branch becomes possible. It is ossified in over 10% that may interfere with some percutaneous denervation techniques [2] (Fig. **1**). Relative position of Kambin's triangle. [Blue triangle] (Fig. **2**).

Target for medial branch ablation is the blue circle (1) on the process and (2) over the roof of foramen. The medial branch, however, can also be ablated in the foramen as it traverses along the foraminal ligament to innervate the facet below at the cephalad aspect of the superior articular process leading to the axilla of the spinal segment. The nerve can be visualized and transected, providing relief of back pain when operating by foraminal decompression for stenosis. These nerves

* **Address correspondence to Anthony T. Yeung:** Department of Neurosurgery, University of New Mexico, School of Medicine, Albuquerque, New Mexico, Desert Institute of Spine Care, Phoenix, Arizona, USA; E-mail: ayeung@sciatica.com

Federico Landriel and Eduardo Vecchi (Eds)

can be mistaken for furcal nerves, but if less than 1 mm in size, they can be safely ablated with no adverse sequel except for relief of preoperative back pain [3].

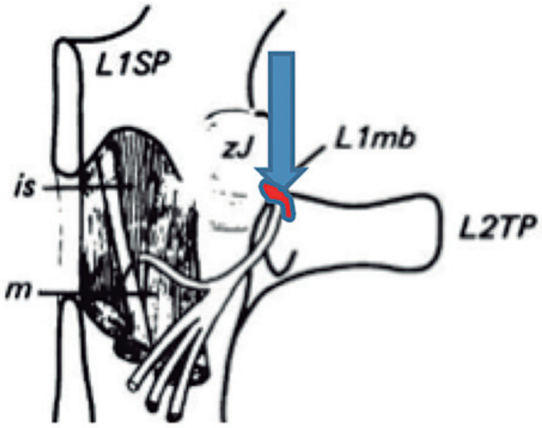

Fig. (1). Target, the medial branch is shown by blue arrow, red is mal. it forms roof of a tunnel in which medial branch passes to facet.

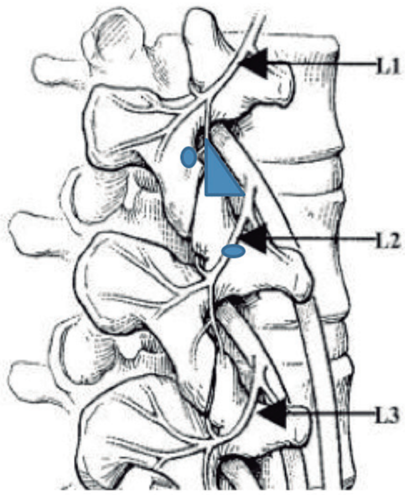

Fig. (2). Relative position of kambin's triangle (blue triangle). Target for medial branch ablation is the blue circle 1 on the process and 2 over the roof of foramen.

The facet joints are not a single or primary source for low-back pain in the patients. It is a part of the degenerative process affecting the functional spinal unit, which includes the disc [4]. If we see a patient with axial back pain Age >65, pain relieved by lying down, pain not increased by coughing or flexion, but increasing in rising from a flexed position, and aggravated by extension and rotation, it may be related to the facet joint [5]. A test to confirm the origin of facet pain is to relieve it by injection of the facet joint or the medial branch with local anesthetic.

The prevalence detected by blocks of facet joint pain is 27% to 40% of the patients with chronic low back pain without disc displacement or radiculitis and with a false-positive rate of 27% to 47% with a single diagnostic block. Datta *et al*. published evidence for diagnosis of lumbar facet joint pain with controlled local anesthetic blocks [6]. 50% relief of pain is used as standard to select patients for denervation in generally accepted published management guidelines. Some feel that more stringent criteria may mar local blocks' utility [7]. Facet joint pain may be difficult to diagnose and confirm in absence of blocks. Medial branch blocks are considered superior to pericapsular blocks but both works [8]. Efficacy of denervation has been questioned in some studies [9].

INDICATIONS AND CONTRAINDICATIONS, PATHOLOGY AND IMAGING INDICATIONS

Imaging is used to determine whether the disc and other known pain generators can contribute to axial back pain as well. The location of the intermuscular cleavage plane between the multifidus and longissimus muscles provide surgical access to the branches of the dorsal ramus [10, 11].

The blue circle is the target on the transverse process and the medial branch, and the blue rod indicates surgical plane access by the endoscope and ablation tools such as bipolar radiofrequency or laser (Fig. **3**).

SURGICAL TECHNIQUE

The video demonstrates the access to groove between transverse process just lateral to the wall of the pedicle or the SAP on lateral side of the body. Target is at intersection of a line crossing and bisecting transverse processes and a lateral

CHAPTER 37

Lumbar Posterior Dynamic Stabilization with Interspinous Devices

Alejandro Mercado Santori*, Fabricio Beccaceci, Mauricio Fernandez, Fabian Cremaschi

Department of Neurosurgery, Spine Center, Hospital Militar, Mendoza, Argentina

Keywords: Intersinous devices, Interspinous surgical video, Lumbar stabilization, Neural decompression.

ADVANTAGES

- Preservation of as many vertebral anatomical structures.
- Minimal involvement of the range of motion (ROM), as only limited flexion and extension in an insignificant degree.
- Stabilization of the level (one or more than one) is engaged, preventing complications related to fusion procedures (*e.g.* nonunion).
- Allows no difficulty performing revision surgeries, with or without preservation of the implant.
- Stopping and, in some cases, reversal of degenerative disc cascade, both the level committed and adjacent levels, to restore the physiological load distribution (there have been many cases of the level disc rehydration affected).
- Current market availability of multiple implant designs, feasible to be selected for each particular case.
- Surgical technique simple, fast and clean, with a short learning curve.
- Low perioperative morbidity related to the implant.
- Quick patient´s return to normal activities.

DISADVANTAGES

- Durability of long-term implant under study.

* **Corresponding author Alejandro Mercado Santori:** Department of Neurosurgery, Spine Center, Hospital Militar, Mendoza, Argentina; E-mail: amercado_santori2000@hotmail.com

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- Results little blunt when interspinous device placement technique is not associated with spinal canal recalibration (bone decompression - laminoforaminotomy) in cases of lumbar stenosis.
- Lack in the world literature of a prospective, multicenter, randomized trial that proves through a good methodology design, overlapping advantages over lumbar fusion techniques.

INDICATIONS

- Spondylotic lumbar stenosis associated with mild to moderate intermittent neurologic claudication, single or multisegmental, central or lateral, in both young and elderly patients.
- Degenerative disc disease: lumbar disc herniation with or without neural foramina stenosis (Fig. **1**).

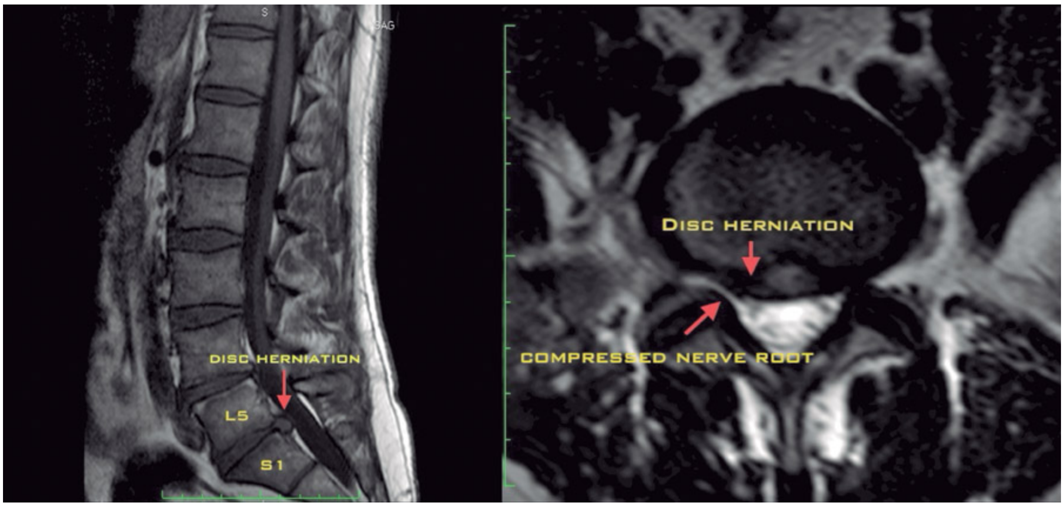

Fig. (1). Sagittal and axial view of the lumbar disc disease at L5-S1, with right nerve root compression.

- Facet syndrome refractory to conservative treatment.
- In large rigid fixation (*e.g.* transpedicular fusion) such as preventive adjacent segment degeneration.
- Mild segmental intraoperative instability.

CONTRAINDICATIONS

- Severe segmental instability.
- Spondylolisthesis greater than or equal to Grade II (Grade I: It's discussed. We don't recommend it).
- Spinal instability secondary to fracture of any type (AO Spine Classification).
- Concomitant infection of any kind (*e.g.* spondylodiscitis).
- Severe scoliosis or kyphosis.
- Osteoporosis (relative contraindication).
- Patients with mental disorders or employment litigation.

PRE OPERATIVE

Patient selection is based on clinical findings (symptoms), imaging (CT + X-rays + MRI) and electrophysiological studies (EMG), excluding those with other morbidities in which this technique is contraindicated. Determination of irreversible and progressive nature of refractoriness to nonoperative treatment (after 16 weeks).

OPERATING ROOM

1. Radiolucent operating room table.
2. Basic spine tray.
3. Fluoroscopy.
4. Headlight and loupes.
5. High-speed drill.

SURGICAL TECHNIQUE

The patient is placed under general anesthesia, with antibiotic prophylaxis (Cephalothin 1g every six hours). In prone position, with pads at the level of iliac crests and chest, abdominal area free. Skin antisepsis. Skin infiltration with lidocaine 1% .

Midline skin incision is performed on the levels to treat (fluoroscopy prior to incision) with no. 24 blade to see the muscle fascia (a Cobb elevator is utilized to sweep the subcutaneous tissues away from midline). Bilateral paravertebral fascia

CHAPTER 38

Cortical Bone Trajectory Pedicle Screw Fixation Mast Technique

Matthew T. Neal, Analiz Rodriguez, Charles L. Branch Jr.*

Department of Neurosurgery, Wake Forest Baptist Medical Center Winston-Salem, NC, USA

Keywords: CBT technique, MAST technique, PLIF surgery.

GENERAL ASPECTS

The pedicle screw is a standard fixation strategy in the lumbosacral spine. A variation of the traditional pedicle screw, the cortical bone trajectory (CBT) pedicle screw, has recently been described. In contrast to the traditional pedicle screw, the CBT screws have a medio-lateral-superior trajectory. This trajectory allows for enhanced cortical bone-screw thread purchase. A cadaveric study revealed that the uniaxial pullout strength of CBT screws was 30% higher than traditional pedicle screws [1]. In another cadaveric model, the CBT screw-rod construct and traditional pedicle screw-rod construct had comparable stability with flexion-extension and lateral bending when an intact disk was present [2]. In addition, the medial starting point for CBT screws requires less soft tissue dissection and interruption of adjacent facet joints.

INDICATIONS / CONTRAINDICATIONS

In general, the indications for CBT screws are the same as those for traditional pedicle screws with lumbar degenerative pathology. Such indications would include an unstable motion segment, recurrent disk herniation, adjacent level degeneration, and pseudoarthrosis. In a forthcoming report describing a clinical cohort of 56 patients, our most common indications for surgery were spondylolisthesis, lumbar stenosis with instability, and recurrent disk herniations.

* **Address correspondence to Charles L. Branch Jr.:** Department of Neurosurgery, Wake Forest Baptist Medical Center Winston-Salem, NC, USA; E-mail: cbranch@wakehealth.edu

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Contraindications would include cases where competent pedicles are lacking (fractured pedicle, pedicle affected by neoplastic or infectious process) or when screw starting point at junction of pars and transverse process is absent from prior decompression.

SURGICAL TECHNIQUE

For single level operations, a midline incision measuring approximately 30-40 mm in length is made over the disk space of the operative level. For multilevel operations, the incision should be lengthened. The fascia over the paraspinal muscles is incised in the midline. We use the minimal access spinal technologies (MAST®) Midline Lumbar Fusion (MIDLF™) system (Medtronic, Minneapolis, MN) for retraction. The speculum retractor is used to bluntly dissect muscle from the spinous processes and laminae of the operative levels. The ruler on the side of the speculum retractor is used to determine the length of the MAST retractor blades that will be needed. The speculum retractor is rotated 90 degrees and opened. The MAST retractor blade is inserted over the operative disk space and between the blades of the speculum retractor. The MAST retractor blade is inserted on the contralateral side using the same steps. The MAST blades are attached to the retractor, and the retractor is opened exposing the operative corridor. At this point, the light source may be attached to the retractor, and the operation can be completed using loupes. The operative microscope can be used as an alternative.

Starting on one side, the inferior facet of the superior vertebral level to be fused is amputated using an osteotome and mallet. The amputated facet is then removed using a large pituitary rongeur. The exposed superior facet of the inferior vertebra to be fused is then removed using a Kerrison rongeur. The medial and superior borders of the pedicle at the inferior level are identified. The yellow ligament and soft tissues are also removed with the Kerrison rongeur to expose the dura and disk space. For the bilateral PLIF, the same steps are repeated on the contralateral side.

The annulus of the disk is incised. The disk material and fibrous attachment to the endplate are removed with pituitary rongeurs and down pushing curettes. The disk space is gradually restored to its normal height with sequential disk space dilators. A template is used to determine the size of the interbody device. Morselized autograft is inserted into the central disk space and then, depending upon which TLIF or PLIF technique is used, one, or both of the interbody devices is inserted with caution to avoid injury to the traversing or exiting nerve root.

The starting point of the cortical bone screw is approximately 1 mm inferior to the transverse process on the lateral aspect of the pars interarticularis (Fig. **1**). The trajectory of the screws is caudocephalad and mediolateral (Fig. **2**). A previous morphometric study of CBT screws revealed the lateral angle was 8° to 9° and the cephalad angle was 25° to 26° [3]. These are the same approximate angles we use. The entry point and the trajectory are confirmed during the pilot hole drilling using the C-Arm fluoroscopic imaging.

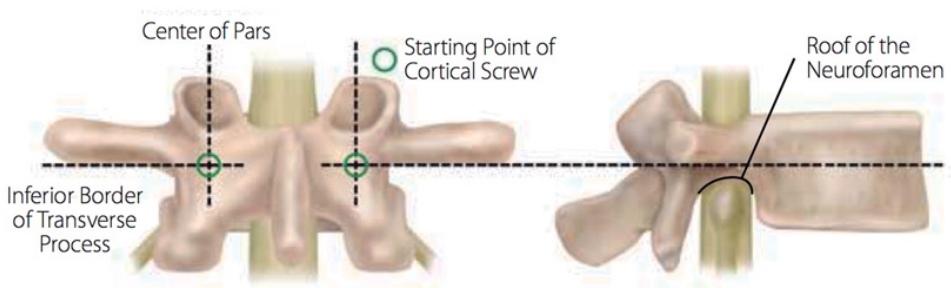

Fig. (1). Cartoon showing starting point for cortical bone screws.

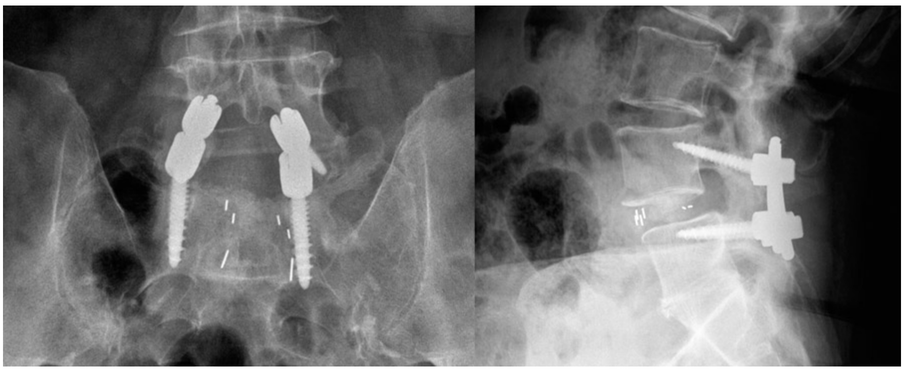

Fig. (2). AP and lateral x-rays showing trajectory of CBT screws.

CHAPTER 39

Percutaneous Lumbar Transfacet Screw Fixation

Hasan R. Syed*, Jean-Marc Voyadzis

Department of Neurosurgery, Medstar Georgetown University Hospital, Washington, DC, USA

Keywords: Minimally invasive, Percutaneous, Transfacet screw, Transfacet screw video.

GENERAL ASPECTS

Transfacet screw fixation in the lumbar spine was first described by King in 1948 [1] and more than a decade later by Boucher, when he reported the use of longer screws as a means of achieving primary fusion in 1959 [2]. He described a starting point on the medial edge of the inferior facet with an oblique trajectory through the joint and towards the pedicle of vertebra below. Magerl demonstrated a variation of transfacet lumbar fixation in 1984 that involved entering the contralateral lamina and directing the screw through the ipsilateral facet joint to terminate at the base of the transverse process [3].

Transfacet fixation in the past decade has gained popularity due to advances in minimally invasive and percutaneous techniques with the potential for less morbidity. A number of biomechanical studies have shown that transfacet screws are nearly equivalent to pedicle screw and rod constructs in providing fixation and resistance to standard loading stressors [4 - 6]. Furthermore, the medial to lateral trajectory of screw placement reduces the risk of canal violation, nerve injury, and cerebrospinal fluid leak compared to pedicle screws. Percutaneous transfacet screw placement represents an attractive alternative for posterior lumbar fixation that minimizes tissue disruption and can lead to a reduction in operative time, blood loss, and length of hospital stay [7].

* **Address correspondence to Hasan R. Syed:** Department of Neurosurgery, Medstar Georgetown University Hospital, Washington, DC, USA; E-mail: syedhr@vcu.edu

Federico Landriel and Eduardo Vecchi (Eds)

INDICATIONS

Transfacet screw fixation is indicated as an adjunct to lumbar interbody fusion approaches. This technique can be used to supplement anterior (ALIF), lateral (LLIF) or posterior lumbar interbody fusions (TLIF, PLIF) for the treatment of degenerative disc disease, low-grade spondylolisthesis, or mechanical back pain [8, 9].

CONTRAINDICATIONS

The use of transfacet screws is contraindicated in patients with isthmic spondylolisthesis, advanced degenerative spondylolisthesis (Grade 2 or higher), significant mechanical instability, severe scoliosis or abnormal or altered facet complex anatomy. Caution should be exercised when placing transfacet screws in a patient with a history of prior laminectomy and medial facetectomy as this may increase the risk of canal violation and affect the ability to achieve proper bony fixation. Preoperative evaluation of facet joint anatomy is recommended in these circumstances.

The placement of transfacet screws at L2 and above is more difficult due to the increasing sagittal angulation of the facet joint. The patient's natural thoracic kyphosis may also complicate screw placement at more rostral lumbar levels. A hyperlordotic lumbar spine may complicate screw placement at the lumbosacral junction.

SURGICAL TECHNIQUE

The Boucher technique for transfacet lumbar screw placement has been previously described [7, 10]. The patient is typically positioned prone, although screw placement in the lateral position can also be performed [7]. A 1.5-cm midline incision is planned over the spinous process two levels above the disc space of interest. Fluoroscopic images are obtained to clearly define the end plates and pedicles of the index segment. Visualization without parallax is critical to ensure a proper entry point on an anteroposterior (AP) view. The proper screw insertion point for a lumbar transfacet screw in this AP view is described as the intersection of a vertical line drawn at the medial aspect of the pedicles with a horizontal line representing the inferior endplate of the superior vertebra being fused. The proper angle of the Jamshidi needle is confirmed in the lateral view through the facet joint and into the pedicle of the inferior vertebra. The trajectory of the screw should place the tip at the inferolateral corner of the pedicle in the AP view and the transition point of the pedicle and vertebral body in the lateral view. This should result in the screw being caudally angulated 30 degrees and laterally angulated 15 degrees [10].

Once the incision is made, the fascia adjacent to the spinous process is detached with electrocautery bilaterally. After the entry point and trajectory are identified in the AP and lateral positions, a Jamshidi needle is docked using fluoroscopic imaging and secured in place with a mallet. The inner stylet is removed, and a Kirschner (K) wire is driven across the facet joint and inferior pedicle with AP and lateral fluoroscopic guidance. Dilators are then introduced over the K-wire. A cannulated drill and tap are passed over the K-wire, followed by the insertion of the cannulated transfacet screw. After fluoroscopic imaging confirms proper placement, the screw can be compressed against the facet joint, and the K-wire is carefully removed (Perpos, Interventional Spine). The contralateral transfacet screw is placed in a similar manner using the same incision. The wounds are closed in standard fashion.

COMPLICATIONS

Potential complications resulting from transfacet screw fixation include nerve injury from aberrant placement in the canal or foramen, cerebrospinal leak, screw or guide-wire fracture, screw pullout, disruption of the facet complex, and K-wire related injury to the abdominal vessels and viscera. In addition, a lateral starting point on the facet complex will prevent incorporation of the inferior facet and result in futile fixation.

POSTOPERATIVE MANAGEMENT

The placement of transfacet screws should not adversely affect the postoperative course following lumber interbody fusion. Routine postoperative care, including pain control, early ambulation, and physical therapy is the mainstay of recovery. Lumbar bracing is an option to facilitate arthrodesis. Routine X-ray imaging

CHAPTER 40

Posterior Dynamic Stabilization

Ali Fahir Ozer[1,*], Deniz Erbulut[1,2]

[1] *Koc University Medical School, Neurosurgery Department, Istanbul, Turkey*

[2] *Koc University Mechanical Engineering Department, Istanbul, Turkey*

Keywords: Dynamic transpedicular stabilization, Dynamic rod video, Hinged screw, Segmental instability.

GENERAL ASPECTS

Fusion surgery was first performed to treat Pott's disease by Hibbs [1] and Albee [2] at the beginning of the 19th century. Fusion surgery is currently used by spinal surgeons throughout the world. It has been proposed as a treatment for other spinal pathologies, particularly trauma and degenerative diseases of the spine, and it is accepted as the gold standard for almost all spinal pathologies, excluding a few selected examples. This technique is valid for overt instability cases such as trauma or isthmic spondylolisthesis. Most of the patients typically present at spine centers with back pain as their only symptom, and are neurologically normal. While there is no absolute indication for surgery, a surgical decision is often made by the patient because they feel that their daily lives are negatively affected as a result. Fusion surgery, even as a minimally invasive approach, has the potential risk of serious complications, including death. To find an appropriate treatment, we should understand segmental instability, which is the main pathology of chronic instability.

SEGMENTAL INSTABILITY

A motion segment consists of two adjacent vertebrae and includes an intervertebral disc, facet joints, capsular ligaments, and anterior and posterior ligamentous complex. This minimal unit is a small sample of a whole spine and

* **Address correspondence to Ali Fahir Ozer:** Koc University Medical School, Neurosurgery Department, Istanbul, Turkey; E-mail: alifahirozer@gmail.com

Federico Landriel and Eduardo Vecchi (Eds)

represents the same functions. The beginning of the degeneration of this unit can be considered to constitute the beginning of segmental instability, which may in turn lead to back pain.

According to the American Academy of Orthopedic Surgeons [3], instability is related to abnormal motion under physiological loads, which can be characterized by the motion segment.

Stokes and Frymoyer [4] defined segmental instability as greater displacement than is seen in a normal structure. Panjabi [5] defined segmental instability as an abnormal motion range in the neutral zone. The physiological range of intervertebral motion is in the range of neutral and elastic zone combination. The neutral zone is defined as a neutral position of the segment in which little resistance is produced [6]. The elastic zone occurs after the neutral zone and continues until the end of the physiological motion range; motion in this range is subject to high resistance [7]. The increase in the neutral zone of a single functional unit is formally known as segmental instability [5].

Panjabi indicated that there are three subsystems relevant to maintain instability. The first, the osteoligamentous system, is accepted as a passive system that acts to prevent abnormal motion of the functional segments. This system consists of an anterior and posterior ligamentous complex, capsular ligaments and the annulus fibrosus. The second, the musculotendinous system, is known to be an active system that acts *via* the muscles by increasing tension and fixing the motion of each segment actively. The third subsystem is the neural subsystem, in which tendons act as transducers by alerting changes in position and providing feedback to the neural control subsystem. Segmental instability is developed if one of these systems is out of order and the other two systems cannot compensate for the dysfunctional subsystem.

INDICATIONS

Most patients who exhibit segmental instability have no neurologic deficits, and pain is their most prominent symptom. However, the quality of life of these patients may decline as a result of this symptom. These patients are unable to participate in an exercise program developed to improve stabilization due to the constant pain.

The following are the main causes of segmental instability:

- Painful back disc
- Degenerative spondylolisthesis
- Recurrent disc herniation
- Lumbar canal stenosis
- Adjacent segment disease
- Carriage type II or III annular tear with or without disc herniation

CONTRAINDICATIONS

Highly developed instability cases are the main contraindications for the usage of dynamic stabilization. Examples of main areas are as follows:

- Unstable spinal trauma
- Unstable spine infections
- Unstable spine tumors
- Isthmic dysplastic spondylolisthesis.

TREATMENT

Medical

For chronic instability cases, the treatment is based on a back exercise program. Our recommendation is “core back exercise” [8]. It is important to develop an exercise program that can be performed easily at the beginning of the pathology. During this phase, painful attacks can be seen once or twice in a year, or continuous pain can be tolerated. Compensatory action of the subsystems can be utilized to support the failing subsystem during first phase of degeneration. In the progressive phase of degeneration it is almost impossible to do back exercises with concurrent back pain. Swimming is inadequate to increase the capacity of the musculotendinous system and should therefore be accompanied by back exercises. Analgesics and anti-inflammatory drugs have no effect in the treatment of the main pathology. They are used in the treatment of acute painful attacks.

CHAPTER 41

Surgical Approach to the Anterior Lumbar Spine

Ashish Khurana[2,*], **Masood Shafafy**[1], **Nasir A. Quraishi**[1]

[1] *Centre for Spinal Studies and Surgery, Queens Medical Centre Campus of Nottingham University Hospitals NHS Trust, Nottingham, UK*

[2] *Aneurin Bevan University Health Board, New Port, South Wales, UK*

Keywords: ALIF video - Anterior lumbar spine access.

INDICATIONS

The anterior approach to the lumbar spine has been shown to be versatile allowing excellent exposure, visualisation and importantly space to perform the procedure being undertaken. In anterior lumbar surgery, there is no disruption of the paravertebral muscles and ligaments. This approach is therefore, commonly used for the treatment of degenerative disc disease (DDD), spondylolisthesis, tumour, infection and fracture. With further development of bone graft substitutes and disc replacements, this exposure promises further growth.

Contraindications may include abnormal vascular anatomy, very large patients and clotting abnormalities. It is worth noting that with complex procedures such as tumour resections, infections and revision, the anterior lumbar approach although not contra-indicated, does lead to a higher complication rate.

Operating Room Set-up

The patient is positioned supine on a standard operating table, and the entire lower abdomen is prepped and draped from the xiphoid to the pubis. The table should be slightly hyperextended.

A urinary catheter is inserted, pressure points padded, slight flexion on knees (to

* **Address correspondence to Ashish Khurana:** Aneurin Bevan University Health Board, New Port, South Wales, UK; E-mail: Ashish.khurana@doctors.org.uk

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reduce tension off psoas muscle), arms abducted allowing easy access to the anaesthetic team. We prefer to use a pulse oximeter on the left big toe, which measures blood flow to the left foot, which is particularly useful when the left common iliac artery is retracted for exposing the L4/5 level (Fig. **1**).

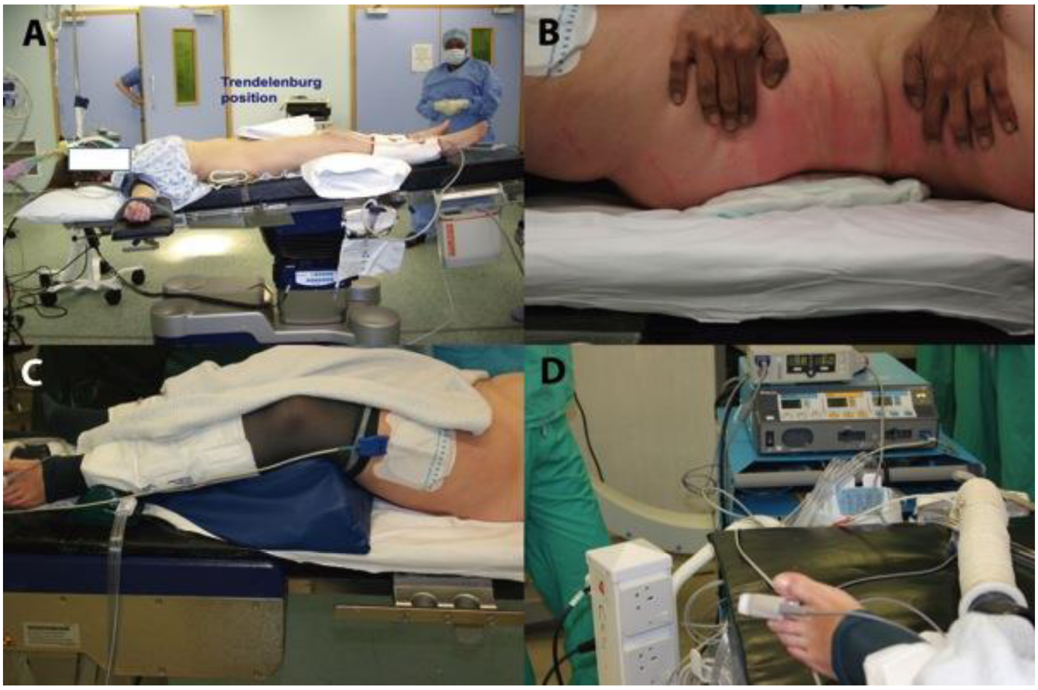

Fig. (1). A. Patient positioning on operating room table. **B.** The entire lower abdomen is prepped and draped from the xiphoid to the pubis. **C.** Slight flexion on knees (to reduce tension off psoas muscle). **D.** A pulse oximeter on the left big toe, which measures blood flow to the left foot.

Surgical Approach

The retroperitoneal approach, which we favour, is performed through a paramedian incision (rather than anterolateral). The intended level is marked with the aid of fluoroscopy - as a general rule, the L5/S1 level lies halfway from the pubic symphysis and umbilicus; the L4/5 level halfway between this point and the umbilicus (Fig. **2**). The incision can be either a longitudinal paramedian incision or through a transverse Pfannenstiel's incision. The first provides exposure through the linea alba or rectus sheath, whereas the second is more cosmetic but provides a more limited exposure unless the rectus muscles are transacted.

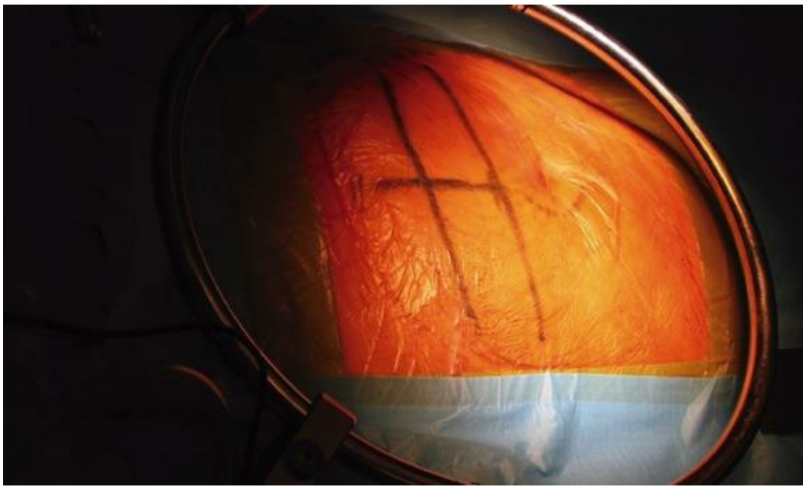

Fig. (2). Level/incision markings for L4/5 and L5/S1 levels. Note that we have already placed our (preferred) Synframe retractors so that the clamps can be positioned accordingly.

After the skin incision and subcutaneous dissection incision (we favour a longitudinal incision, in case extension is required), the anterior rectus sheath is incised (Fig. **3**). This exposes the (left) rectus muscle, which is retracted laterally (ie. to the left) to allow exposure of the peritoneum.

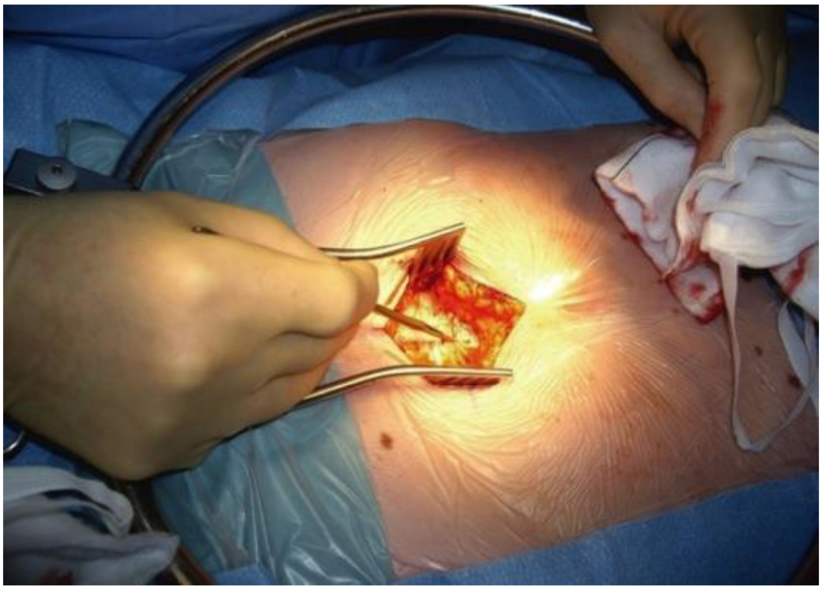

Fig. (3). Incision of anterior rectus sheath.

CHAPTER 42

Transpsoas Approach for Thoracolumbar Interbody Fusion - XLIF

Luiz Pimenta[1,2,*], Luis Marchi[2]

[1] *Department of Neurosurgery, UCSD San Diego, California, USA*

[2] *Department of Neurosurgery, Instituto de Patología da Coluna (IPC), São Paulo, Brazil*

Keywords: Lateral access, LLIF video, Minimally invasive spine surgery, Transpsoas approach.

INDICATIONS AND CONTRAINDICATIONS

Spinal arthrodesis has been proved to be a safe and effective surgical option for segmental spinal problems such as instability, painful discogenic disc disease, scoliosis, spondylolisthesis, and other several spinal conditions [1]. The advent of minimally invasive spine surgery allowed the achievement of good clinical and radiological results while minimizing collateral muscle and bone damage, with decreased risks and complications [2]. One of these techniques is the extreme lateral interbody fusion (XLIF), which was first indicated to treat degenerative disc disease above L5 level, without severe central canal stenosis [3]. The development of the technique and its related instruments allowed the advance of indications, evidencing the achievement of indirect neural decompression by disc height restoration [4], and vertebral body derotation and coronal alignment obtained by ligamentotaxis [5]. Other current indications for XLIF, with or without pedicle screw supplementation, are adjacent level disease, pseudoarthrosis, discogenic low back pain, trauma, infection, sagittal alignment and spondylolisthesis [6].

* **Address correspondence to Luiz Pimenta:** Department of Neurosurgery, UCSD San Diego, California, USA; E-mail: luizpimenta@luizpimenta.com.br

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SURGICAL TECHNIQUE

Patient is placed and taped in a true lateral position in a radiolucent table. A mark is made in the skin based on fluoroscopy that identifies the index level. Then, a 3-4 cm longitudinal single skin incision is made, over the intersection between the posterolateral muscles of the abdominal wall. The first fascia incision is made posteriorly to allow the surgeon to introduce the index finger into the retroperitoneal space, providing a safe lateral entry. Next, a second fascia incision is made below the first skin mark to introduce the initial dilator guided by surgeon´s index finger, in order to safely escort the dilator up to the psoas muscle, protecting intra-abdominal contents.

To safely cross the psoas muscle, a free-run electromyography (EMG) is used during all passage through the psoas muscle, retractor expansion, and instrument implantation. Under direct visualization, a wide discectomy can be performed with standard instruments. The anterior and posterior portions of the disc containing the longitudinal ligaments are preserved with discectomy focused on the center of the disc, with a sufficient AP dimension to accommodate a large implant, offering the opportunity to place an implant that covers both side edges of the cortical apophyseal ring, maximizing the spinal plateau support. The complete removal of cartilage and rasping of the cortical bone layer are essential to provide blood precursor cells and bone growth factors for the successful bone ingrowths.

After closing the operative wound in a standard fashion, the patient can be positioned in ventral decubitus for standard supplemental internal fixation utilizing posterior percutaneous pedicle screw fixation, if needed.

COMPLICATIONS

Literature mostly shows low rate of complications in the immediate postoperative period, including hip flexion weakness or numbness ipsilateral to the surgical access (psoas weakness), and less frequently sensory changes in the lower limb, all resolved within 6 months [1, 4, 7]. Subsidence is another well described complication related to anterior fusion surgery. It is usually related to standalone constructs, and has been correlated to instability at the index level, possibly due to resectioning of the anterior and posterior longitudinal ligaments. Subsidence decreases distraction of the disc space and the indirect decompression of the neural structures. Also, it can cause a spinal imbalance, not reaching the proper correction of sagittal alignment. The implantation of wider interbody spacers by lateral approach has been proved to maximize the endplate support and allow a standalone construction with a lower incidence of severe cage subsidence, preventing acute pain onset, and preserving surgical gains such as disc space distraction, sagittal alignment, and their effects on neural decompression [8].

The published rate of complications in lateral approach varies considerably, and is related to a not standardized definition of complications inherent to the approach. For complication avoidance, surgeon´s education is mandatory, as the procedure has growth indications with the development of novel instrumentations, and learning curve must be respected to minimize risks and increase surgery success rates. Rodgers *et al*. [9] found that patients with comorbidities were no more likely to have complications than those without comorbidities. Likewise, the inclusion of the L4–L5 level proved to be a factor, independently of how many levels were included. Also, fusion surgery was a statistically significant component in the incidence of complications.

POSTOPERATIVE MANAGEMENT

Patients must be encouraged to walk the same day to aid their recovery and muscle function, also avoiding deep venous thrombosis and pulmonary thromboembolism [10]. Postoperative pain tends to be minimal, and patients may be discharged after only an overnight hospital stay. Postoperative rehabilitation of the ipsilateral psoas muscle should be conducted during the first few postoperative days to reduce transitory hip flexion weakness. Postoperative thigh discomfort is usually uneventful, and slight lateral thigh numbness rare. These symptoms are typically resolved completely within four to six weeks in all cases. Patients that need postoperative intensive care or blood transfusion are very unusual.

OUTCOMES

One of the biggest advantages of the lateral approach is the possibility to use larger implants that are placed in the densest area of the vertebral endplate,

CHAPTER 43

Minimal Invasive Posterior Lumbar Interbody Fusion (MIS PLIF)

Moon Seok Kim*, Joon Young Kim, Il Sup Kim, Jae Taek Hong

Department of Neurosurgery, St. Vincent's Hospital, Catholic University of Korea, Korea

Keywords: Cortical bone trajectory screw, Minimally invasive, MIS PLIF video, PLIF surgical technique.

GENERAL ASPECTS

The posterior lumbar interbody fusion (PLIF) was thought to be first introduced by Jaslow [1] in 1946, and Cloward presented his 100 cases [2] in 1953. While this technique increased in popularity because of its ability to achieve 360-degree arthrodesis from a single posterior approach, it requires significant neural retraction for disc space preparation and cage/bone graft insertion. Also, midline back muscle damage is inevitable in this procedure. Since the concept of a unilateral approach to the anterior column was developed by Harms in 1998, transforaminal lumbar interbody fusion (TLIF) has gained more popularity as an alternative to PLIF for obtaining a circumferential fusion through a unilateral approach at a more lateral angle and with the minimal expenditure for the retraction of the traversing root [3 - 7]. The disadvantages of TLIF are, first, the incomplete removal of intervertebral disc potential occult injury to exiting nerve root. Also, TLIF is unable to decompress the opposite nerve root. This may require contralateral laminotomy. Moreover, paramedian approach for TLIF procedure needs additional skin incision for contralateral instrumentation.

Recently, lumbar spinous-splitting laminectomy for the lumbar stenosis has been reported as a good surgical option to reduce acute postoperative wound pain and

* **Address correspondence to Moon Seok Kim:** Department of Neurosurgery, St. Vincent's Hospital, Catholic University of Korea, Korea; E-mail: onlyone007@hotmail.com

Federico Landriel and Eduardo Vecchi (Eds)

prevent postoperative muscle atrophy [8 - 10]. And the novel cortical bone trajectory technique can be used to avoid extensive tissue dissection by limiting the surgical corridor [11, 12]. The cortical bone trajectory technique involves a starting point on the medial aspect of the pars and angulation of the pedicle screw in a mediolateral and caudocranial direction. This medio-latero-superior trajectory may limit dissection of the mobile superior facet joint and reduce incision length and muscle dissection, thus minimizing approach-related trauma during pedicle fixation.

Using these current concepts of decompression and instrumentation, we can minimize the tissue damage and overcome the disadvantages of PLIF/TLIF procedure. This chapter highlights some of the technical aspects of minimal invasive PLIF and its associated perioperative considerations.

INDICATIONS AND CONTRAINDICATIONS

Surgical indications of MIS PLIF are the same as those of open PLIF to stabilize the spine in almost all situations including degenerative, traumatic, infectious, and neoplastic pathologies. However, prior to MIS PLIF, the surgeon should have sufficient experience with the open PLIF procedure.

Indications

- Totally degenerated disks with marked instability
- Lumbar spondylolisthesis (both degenerative and isthmic, Grade I and II)
- Recurrent disc herniation
- Pseudoarthrosis of transverse process fusion
- Back pain due to symptomatic spondylosis
- Symptomatic degenerative disc disease
- Degenerative scoliosis

Contraindications

- Overt infection
- Previous anterior lumbar interbody fusion
- Bony destructive neoplasm

PREOPERATIVE PREPARATION

Prior to surgery, confirmatory imaging studies are essential along with a complete history and neurological examination. There should be careful considerations in some factors preoperatively including;

- Preoperative evaluation of the patient´s medical condition
- Confirmation of the anatomical variation and pathology
- Surgical indications of the pathology
- Bone graft preparation (autograft or allograft or biologics)

Anatomy of the pedicle is variable in angulation, size, and pedicle length throughout the spine. The transverse diameter is generally much smaller than the vertical diameter for each pedicle, which demands much greater screw placement accuracy in the transverse plane at each level. In the lumbar spine, the transverse pedicle diameter gradually increases from L1 to L5 (7.4 to 18.3 mm), and the transverse plane lumbar pedicle angle increases from L1 to L5 (25 to 40 degrees).

SURGICAL TECHNIQUE

Patient Positioning and Preparation

Following endotracheal anesthesia, patients are usually placed on a Jackson table in a prone position with the abdomen hanging free to avoid epidural venous distension and minimize blood loss from abdominal distension, and with the hips in extension to allow a lordotic lumbar alignment. Jackson table is radiolucent, thus allowing intraoperative fluoroscopy to identify the placement of the screws and interbody cages. All the pressure points are padded. Prior to preparation and draping, true AP and lateral fluoroscopic images are obtained to identify the involved level and anatomical alignment.

Approach

We describe the technique for one level L4-5 decompression and interbody fusion performed *via* spinous process splitting.

A posterior midline skin incision is made between the L3 and L5 spinous

CHAPTER 44

Open Transforaminal Lumbar Interbody Fusion

Kevin S. Chen*, Anthony C. Wang, Khoi D. Than, Elyne N. Kahn, Frank LaMarca, Paul Park

Department of Neurosurgery, University of Michigan, Ann Arbor, Michigan, USA

Keywords: Open TLIF video, TLIF technique, TLIF surgery.

INDICATIONS AND CONTRAINDICATIONS

Degenerative disc disease and back pain with or without radiculopathy are common conditions that result in a staggering socioeconomic burden [1]. While the majority of cases resolve with conservative management, selected number of patients are likely to derive significant benefit from decompression and/or fusion of the lumbar spine. Lumbar interbody fusion is now a popular option for fusion as arthrodesis rates are high, and the ability to restore disc height as well as improve sagittal and coronal plane mal-alignment represent significant advantages [2].

A number of approaches for lumbar interbody fusion are utilized, including anterior lumbar interbody fusion (ALIF), posterior lumbar interbody fusion (PLIF), and transforaminal lumbar interbody fusion (TLIF) [3]. TLIF is often preferred over other approaches since fusion of both anterior and posterior elements can be accomplished in one stage with diminished risk to vascular and autonomic structures (as compared with ALIF). Furthermore, TLIF requires minimal retraction of the thecal sac, decreasing risk of dural tears, reducing chance of injury to nerve roots and conus medullaris, yet preserving the contralateral facet joint for fusion (as compared with PLIF).

* **Address correspondence to Kevin S. Chen:** Department of Neurosurgery, University of Michigan, Ann Arbor, Michigan, USA; E-mail: kechen@med.umich.edu

Federico Landriel and Eduardo Vecchi (Eds)

Reported indications for TLIF typically include spondylolisthesis, degenerative disc disease, recurrent disc herniation, pseudoarthrosis, post-laminectomy kyphosis, and/or correction of coronal/sagittal deformities [2].

SURGICAL TECHNIQUE

The patient is positioned prone on a Jackson frame. Incision is made in the midline over the target level and carried down to the spinal elements. Subperiosteal dissection is used to expose spinous processes, laminae, and facet joints of the level(s) to be fused. Standard landmarks are used to first place pedicle screws prior to exposure of nerve roots and the thecal sac [4].

To prepare for the TLIF, a laminotomy or laminectomy is performed that is carried through the pars interarticularis on one side, thus separating the inferior articular facet from the lamina (Fig. **1**). Typically this is performed on the most symptomatic side, since removal of the inferior articular facet as well as significant portions of the remaining superior facet results in a robust decompression of the neural foramen. The resected facet can be morselized and used as autograft.

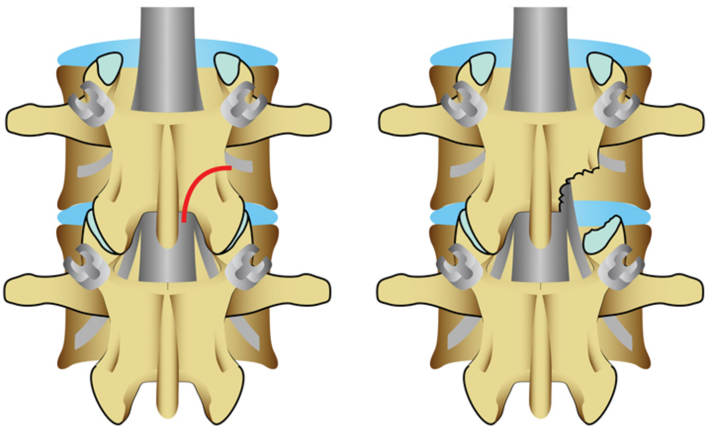

Fig. (1). TLIF begins by performing a laminotomy (or in certain cases a laminectomy) followed by making a cut laterally through the ipsilateral pars interarticularis. In this way, the inferior articular facet can be removed, followed by the superior and medial portion of the remaining superior facet.

In many cases significant stenosis can be a concurrent issue. In such cases, a complete laminectomy with decompression of the spinal canal as well as contralateral neural foramen can be performed concurrently with the TLIF (see accompanying video).

After removal of a portion of the lamina, or in certain cases the complete lamina, with unilateral facet resection and ligamentum flavum removal, the disc space can be identified lateral to the traversing nerve root. The exiting nerve root within the superior portion of the now decompressed foramen can often also be identified. Depending on the anatomy, the traversing nerve root may need to be gently retracted medially, at which point a blade is used to create a "window" into the disc space. If the disc space is completely collapsed, an osteotome can be used to enter the intervertebral disc space. It should be re-emphasized that removal of the inferior facet complex allows generous exposure of the disc space, typically requiring minimal retraction of the nerve root.

As complete a discectomy as possible is performed with a variety of rongeurs and rotating shavers. The endplates are prepared for grafting with raspers and curettes, taking care to preserve endplate integrity. Sequential distraction is then performed with increasingly larger rotating distractors. An interbody cage trial is used to determine cage size. Autograft and/or allograft are placed into the disc space. A final interbody cage filled with autograft or allograft is impacted into the disc space (Fig. **2**).

Rods are then cut, contoured, and inserted through the screw heads. The posterior bone elements are decorticated and autograft and/or allograft are placed for posterior fusion. A drain may be placed, and the wound is closed in layers.

COMPLICATIONS

Reported perioperative complications of TLIF include durotomy, mal-positioned instrumentation, nerve root injury, excessive blood loss, radiculitis, urinary retention, urinary tract infection or other medical complications (*e.g.* pneumonia, myocardial infarction, etc.). Delayed complications include wound infection, hardware failure, pseudoarthrosis, and adjacent segment disease.

CHAPTER 45

Minimally Invasive Transforaminal Lumbar Interbody Fusion (MIS TLIF)

Federico Landriel[1,*], Eduardo Vecchi[1], Santiago Hem[1], Claudio Yampolsky[1], Maximiliano Toscano[1], Roberto C. Diaz[2], Miguel E. Berbeo Calderón[2]

[1] *Neurosurgical Department, Hospital Italiano, Buenos Aires, Argentina*

[2] *Neurosurgical Department, Hospital Universitario Bogota, Colombia*

Keywords: Interbody fusion video, Minimally invasive TLIF, TLIF surgery, TLIF technique.

GENERAL ASPECTS

Posterior lumbar interbody arthrodesis techniques allow decompression and stabilization of the spinal segment through spinal fusion with transpedicular instrumentation. The open transforaminal lumbar interbody fusion (TLIF) is a unilateral approach that permits decompression of central and foraminal stenosis and a 3 column arthrodesis with lower rates of nerve root injury and a single, lateral to medial trajectory, interbody cage placement. Minimally invasive (MIS) techniques for TLIF procedures were subsequently developed with the aims of less soft-tissue damage and intraoperative blood loss, decreased rates of surgical site infection and reducing hospital stay with quicker recovery time [1, 2].

INDICATIONS (RELATIVE*)

- Symptomatic Spondylolisthesis Meyerding grade I o II (6-week failed non-operative treatment)
- Discogenic low back pain
- Neuroforaminal stenosis
- Synovial cyst with instability

* **Address correspondence to Federico Landriel:** Neurosurgical Department, Hospital Italiano, Buenos Aires, Argentina; Email: fedelandriel@gmail.com

- Lumbar deformity less than 3 intersegmental levels
- Recurrent lumbar disc herniation
- Spondylosis with radicular or low back pain
- Reoperation for pseudoarthrosis
- *Patients with comorbidities that are not good candidates for open surgery

SURGICAL TECHNIQUE

Under general endotracheal anesthesia, the patients are positioned prone on a radiolucent table. Somatosensory and motor evoked potentials are monitored. Lateral and anteroposterior (AP) C-arm fluoroscopic images are obtained to ensure that the pedicles could be adequately imaged. Midline, pedicles, disc space are marked and surgical level is confirmed. Skin marks previously determined with fluoroscopy are useful to minimize radiation exposure.

A 3 cm incision is centered at the targeted disc level between the cranial and caudal pedicles; approximately 4 cm lateral to the midline is performed. The approach is made on the side of radicular symptoms or on the more symptomatic side if the patient had bilateral leg pain. A plane is developed between the multifidus and longissimus muscles with blunt finger dissection. A K-wire is docked in the corresponding facet joint and sequential soft-tissue dilators are inserted through the guide-wire until the desired working diameter is achieved (Fig **1**). An expandable tubular retractor is applied.

Either a partial or complete facetectomy from lateral to medial [3] is performed in order to expose the posterolateral aspect of the disc. Using an osteotome, the superior articular process (SAP) is entirely removed first until the ipsilateral ligamentum flavum is visualized. The lateral margin of the ligamentum flavum is removed. Once the SAP is removed the foramen is further enlarged until the traversing nerve root is fully decompressed. The removed bone is denuded of all soft tissues, morselized, and saved for graft material. This approach allows also the decompression of the exiting nerve root, but it is not exposed/visualized needlessly. In cases of severe bilateral foraminal and central canal stenosis, the tubular retractor is angled medially with the patient tilted laterally to facilitate the remotion of the contralateral lamina and overgrown facet, thus directly decompressing the contralateral nerve roots.

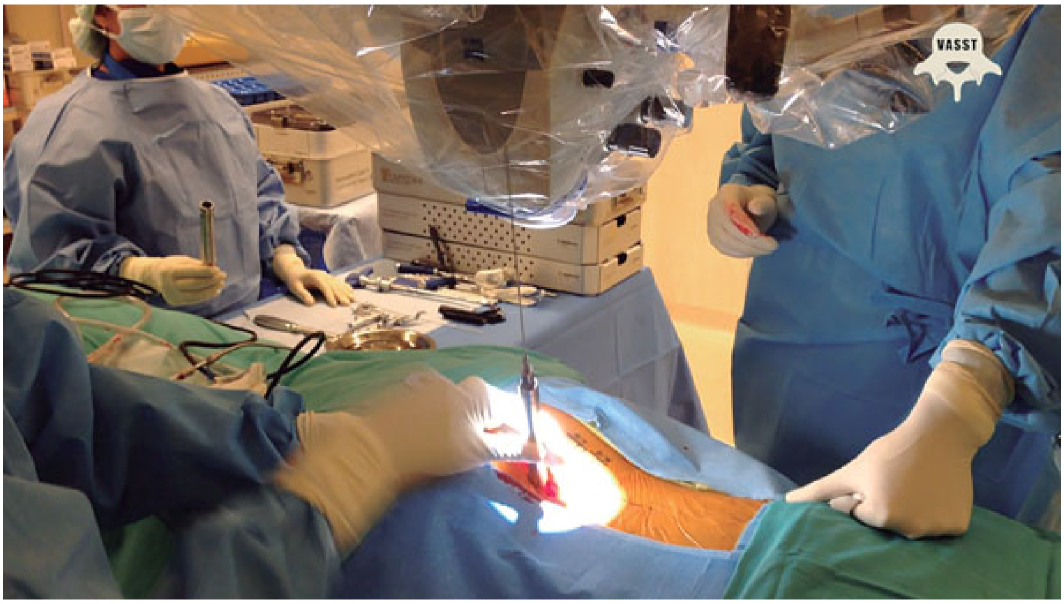

Fig. (1). Intraoperative photograph shows sequential soft-tissue dilators are inserted through the guide wire.

A rectangular annulotomy and subsequent discectomy are performed with minimal, if any, nerve retraction. Disc space shavers of different sizes are used to distract the disc space and prepare it for fusion (Fig. **2**). The cartilaginous material is removed from the endplates with curettes to improve fusion. A mixture of autograft from the facet joint, hydroxyapatite and b-tricalcium phosphate is impacted anteriorly in the disc space. A polyetheretherketone (PEEK) interbody cage packed with autograft is inserted obliquely in the disc space under fluoroscopy guidance. Indirect contralateral foraminal decompression could be achieved with the restoration of intervertebral body height by placing proper interbody cages. Hemostasis and neural elements are controlled. The tubular retractor is removed.

Under fluoroscopy guidance, a Jamshidi needle is inserted into each pedicle and a K-wire is advanced to the two-third point of the vertebral body. In the ipsilateral side the K-wires are placed through the same incision. In the contralateral side, 2 paramedian incisions are made for percutaneous screw placement (Fig. **3**). Percutaneous pedicle screws are placed above and below the segment to be fused. The rods are placed through separate stab incisions and brought into the opening

SECTION IV - TUMORS, CYSTS AND VASCULAR MALFORMATIONS

CHAPTER 46

Intramedullary Tumor Resection

Jacques Brotchi[1], Federico Landriel[2,*]

[1] *Emeritus Professor and Honorary Chairman, Department of Neurosurgery, Erasme Academic Hospital, Brussels, Belgium*

[2] *Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina*

Keywords: Spinal tumor video, Intramedullary surgical technique, Astrocitoma video, Ependymoma video.

GENERAL ASPECTS

Intramedullary spinal tumors are uncommon lesions that account for 5% to 10% of all spinal tumors in adults and approximately 35% in children. About 90% are glial tumors, of which ependymomas and astrocytomas are the most frequent. Ependymomas represent about 60% and astrocytomas 30% of these neoplasms in adults. The intracranial-to-spine ratio for astrocytomas is approximately 10:1, whereas that for ependymomas can range from 2:1 to 3:1, depending on the specific histologic variant [1]. Symptomatic intramedullary tumors without treatment can cause significant neurologic morbidity and mortality.

INDICATIONS

- Symptomatic lesions. In incidental asymptomatic discovery tumors, it is advisable to follow up the patient clinically and with a magnetic resonance imaging (MRI) every 6 months.
- Progression of the lesion size or associated cysts on MRI.

CONTRAINDICATIONS

- We do not recommend operating on a stable lesion in an asymptomatic patient
- Multiple/drop metastasis

* **Address correspondence to Federico Landriel:** Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina; E-mail: fedelandriel@gmail.com

Federico Landriel and Eduardo Vecchi (Eds)

- Avoid surgery in suspicion of multiple sclerosis or transverse myelitis

SURGICAL TECHNIQUE [2]

The patient is positioned prone with rolls under the chest and iliac crests, freeing the abdomen from all pressures. Preoperative corticosteroids and antibiotics are administered. Before the beginning of the operation and positioning, somatosensitive evoked potentials (SEPs) and motor evoked potentials (MEPs) are recorded. For cervical and upper thoracic lesions, three-point head fixation is used to prevent inadvertent cervical flexion.

Approach

Under fluoroscopy guidance skin marks are made focused in the lesion and extending one level above and one level below the rostral and caudal poles of the tumoral mass. A standard posterior midline approach is performed. Subperiosteal dissection through the raphe allows symmetrical retraction of paraspinal muscles. Laminectomy or laminotomy is carefully performed, avoiding any potential injury to the spinal cord. Lateral masses should be preserved, to decrease the risk of postoperative kyphosis. Epidural hemostasis requires as much care as that in the soft tissues. A clean field, without any bleeding, must be established before opening the dura.

The durotomy should be performed under microscope magnification, the arachnoid membrane is preserved intact whenever possible during this maneuver. Dural suspension with simple traction sutures is often sufficient, but sutures to adjacent muscles provide a wider surgical field. Careful opening of the arachnoid is important, so that it is suitable for suturing at the end of the operation. The arachnoid membrane is opened separately with microscissors and gently detached from the posterior or lateral spinal cord surfaces.

Meticulous inspection of the spinal cord under microscopic magnification may reveal subpial color modification by the lesion. Intraoperative ultrasonography could be very helpful for locating solid and cystic parts of the tumor.

A midline myelotomy is performed at least the lesion is situated in one dorsal column and is visible on the cord surface without a cortical “mantle.”

Magnification allows the proper localization of the dorsal median sulcus, over which the posterior spinal vein runs. This posterior sulcus can sometimes be identified only on the basis of the convergence of vessels toward the midline. SEPs cord mapping and direct stimulation may be helpful to identify the posterior dorsal sulcus. The vessels running vertically over the posterior columns are dissected and mobilized laterally.

The posterior columns are gently retracted and opened with scissors and microforceps, over the entire length of the solid portion of the lesion. 6-0 traction sutures between the pia mater and the dura without tension improve the surgical exposure and may reduce the severity of repeated trauma resulting from dissection. It is advisable to monitor SEP to ratify the preservation of optimal posterior column function during these maneuvers. The pressure of the lesion itself sometimes helps keeping the dorsal columns separate without the need of pial traction.

First Surgical Maneuver

The tumor is dissected until a sufficient portion is exposed; a biopsy is obtained with forceps and scissors without coagulation and the sample is sent for frozen section (Fig. **1**).

Second Surgical Maneuver

Tumor debulking is performed using an ultrasonic aspirator. It is advisable to set the suction at the lowest possible level or closed off and vibratory force set at a suitably low level. Once the internal volume of the lesion is reduced, a cleavage plane is search thus avoiding traction or pressure on the spinal cord.

Intratumoral resection is accomplished from inside to outside, and this is sometimes facilitated by the presence of an intratumoral hematoma or cyst. It should also be remembered that the ultrasonic aspirator does not distinguish between tumor and spinal cord, only the surgeon does. The best marker distinguishing tumor from normal cord is color.

CHAPTER 47

Spinal Hemangioblastoma Resection

Mohamad Bydon*, Kyriakos Papadimitriou, Ziya Gokaslan, Ali Bydon

Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA

Keywords: Angiogenic tumor, Spinal hemangioblastoma video, Von Hippel Lindau.

GENERAL ASPECTS

Hemangioblastomas (HB) are rare tumors that account for 2-4% of all spinal tumors [1]. They are benign (World Health Organization grade 1), highly vascular, and either diagnosed sporadically or secondary to von Hippel-Lindau (VHL) disease [2]. In 1927, Arvid Lindau reported the connection between retinal angiomas and hemangiomas of the central nervous system. VHL disease is present in 20-25% of spinal hemangioblastoma cases; it is an autosomal dominant neoplastic syndrome caused by an inherited or germ-line mutation of the VHL gene, an important tumor suppressor, on chromosome 3p25-26 [1, 3]. The mutation of the VHL gene causes a distinctive, multi-system pattern of benign and malignant tumors and cysts, notably in the central nervous system, retina, and kidney.

While hemangioblastomas are found throughout the central nervous system, they are usually located in the posterior fossa, where they represent 10% of all neoplasms in that location [4]. Spinal hemangioblastomas are usually diagnosed in the cervical and thoracic levels; less commonly, these tumors can be found in the filum terminale or the dorsal roots of the lumbosacral spine. About 25-40% of central nervous system tumors in VHL disease are spinal hemangioblastomas, while 20-25% of patients with spinal hemangioblastomas have VHL disease [3].

* **Address correspondence to Mohamad Bydon:** Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA; E-mail: Mbydon1@jhmi.edu

Federico Landriel and Eduardo Vecchi (Eds)

Hemangioblastomas are usually found in men, with a ratio of male to female patients of 1.6:1 to 5.5:1 [3]. Sporadic cases of hemangioblastoma tend to be patients with solitary lesions who are most often diagnosed between 30 and 40 years of age. Conversely, patients with VHL disease tend to have multiple tumors and present between 20 and 30 years of age [3].

MRI is the gold standard to diagnose hemangioblastomas. They are well circumscribed, homogenously contrast-enhancing lesions that are isointense on T1-weighted images and hyperintense on T2-weighted images with edema and syrinx formation commonly seen. On angiography, they appear highly vascular and dense, with prolonged tumor staining and prominent draining vessels.

Managing intramedullary spinal cord tumors remains a challenge [5]. Complete resection is curative for patients harboring a hemangioblastoma, but en bloc removal is a delicate procedure that cannot always be achieved [3]. Similar to other pathologies, the prognosis of intramedullary spinal HB depends on their infiltrative nature, size, recurrence rate, and treatment options [1, 3, 6, 7].

INDICATIONS

- Sensory, motor or sphincter dysfunction.
- Non-mechanical pain exacerbated with recumbency.

CONTRAINDICATIONS

- Concomitant Traverse myelitis.
- Multiple sclerosis.
- Multiple lesions or drop metastases.

SURGICAL TECHNIQUE

General anesthesia is administered and intraoperative monitoring of sensory and motor evoked potentials is used to ensure preservation of spinal cord function. A midline skin incision centered over the lesion is made, with adequate extent to allow retraction of muscle tissue [7]. Laminectomy or laminotomy one level above to one below the level of the tumor should provide adequate surgical corridors [7]. Limiting bone removal is necessary for pediatric patients, for whom a laminotomy is most appropriate; in infants, a unilateral laminectomy is the best approach. If extensive bone removal must be performed, in every fifth or sixth vertebrae the posterior arch is spared to preserve some bony structure. In all cases, care is taken to prevent damage to the spinal cord and to preserve the lateral structures of the vertebrae to avoid postoperative kyphosis. In revision surgeries, removal of scar tissue should be performed with utmost care to avoid tearing of the dura or damage to adjacent neuronal structures and subsequent cerebrospinal fluid leakage [1].

After exposure, meticulous hemostasis is obtained before opening the dura. Large moistened cottonoids are placed along the retracted musculature to prevent epidural oozing. Compression of epidural veins is obtained with surgical strips [7].

A midline dural opening is performed under microscopic magnification and is extended cranially and caudally to expose the tumor in its entirety. Intraoperative ultrasonography can be helpful for further localization if the tumor is not apparent from subpial coloration. If the tumor is located in a single dorsal column and is also evident on the surface of the cord, a paramedian approach may be used [6 - 8]. Dural traction sutures are placed and the arachnoid matter is opened separately and is detached from the posterolateral spinal cord [7]. An electrode is placed on the dorsal columns in order to measure D-wave amplitude. Both sensory and motor evoked potentials (SEPs and MEPs) are monitored to assess spinal cord integrity during the surgical resection.

A midline approach to the tumor is utilized. The posterior spinal vein running in the dorsal median sulcus is a useful landmark [7]. The convergence of vessels on the midline is an alternative landmark [7]. All vessels are dissected and mobilized away from the surgical corridor, particularly in the sulco-commissural region. If the tumor distorts the spinal cord or adheres to the posterior columns, the midline can be unclear at the level of the tumor, necessitating identification of the midline above and below the tumor and interpolation to the level of the tumor. Many intramedullary tumors have a vascular pedicle communicating with the anterior spinal artery, carrying a risk of injury to that artery [7].

CHAPTER 48

Spinal Extramedullary Ependymoma Resection

Joseph Lin*, Mohamad Bydon, Kyriakos Papadimitriou, Ali Bydon

Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA

Keywords: Ependymoma, Epithelioid, Intramedullary tumor, Myxopapillary.

GENERAL ASPECTS

Ependymomas are primary intramedullary tumors derived from the ependyma of the spinal cord, typically in the central canal or periventricular area [1]. They account for 25% of all primary spinal cord tumors [2]. The World Health Organization categorizes ependymomas as grade I (myxopapillary), grade II (the most common, including cellular, papillary, clear cell, or tanycytic), and grade III (anaplastic) [2].

Myxopapillary ependymomas are a histologically distinct subset of ependymomas. The term "myxopapillary" is based on the histologic appearance of these tumors. They produce mucin and the tumor cells are arranged in papillae. Pathologically, myxopapillary ependymomas are characterized by biphasic morphology. Nests of epithelioid malignant cells are interdigitated with myxohyaline material [3]. These tumors are often well circumscribed; typically, they do not infiltrate the adjacent healthy spinal cord tissue [4]. While these tumors tend to be slow-growing, they may disseminate intracranially through the subarachnoid space and be mistaken for other lesions such as medulloblastomas [5, 6].

Myxopapillary ependymomas are almost always found in the spine, typically in the conus medullaris or filum terminale, and account for 20% of tumors found in the cauda equina. Patients tend to be males diagnosed between the ages of 30 and

* **Address correspondence to Joseph Lin:** Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA; E-mail: jlin84@jhmi.edu

Federico Landriel and Eduardo Vecchi (Eds)

40 [4]. Presenting symptoms can range from low back pain or minor radiculopathy to cauda equina syndrome [6]. An acute and precipitous neurological decline may occur due to intratumoral hemorrhage. Subarachnoid hemorrhage is also possible [6].

On MRI, myxopapillary ependymomas are contrast-enhancing, iso- to hyperintense on T1-weighted images (depending on the amount of proteinaceous mucoid matrix), and hyperintense on T2-weighted images. T1-hyperintensity is a distinguishing feature of myxopapillary ependymomas, since other ependymoma subtypes tend to be hypointense on T1-weighted images. Heterogeneous enhancement indicates cyst formation, hemorrhage, or necrosis [7].

Surgical resection is the mainstay of treatment for long-term disease-free survival [2]. Adjuvant radiation therapy is reserved as a potential alternative to re-operation for subtotally resected or recurrent lesions [4]. Recurrence can occur if resection is incomplete or tumor histology is high-grade. Ependymomas that are friable or adherent to the spinal cord are particularly difficult to resect completely [4].

INDICATIONS

- Radicular or dull axial pain and pain on recumbency
- Signs of increased intracranial pressure
- Motor weakness
- Sphincter dysfunction
- Sensory gait ataxia

CONTRAINDICATIONS

- Concominant traverse myelitis or multiple sclerosis
- Multiple lesions or drop metastases [8]

SURGICAL TECHNIQUE

General anesthesia is administered and intraoperative monitoring of sensory- and motor-evoked potentials is used to ensure preservation of spinal cord function. A standard midline incision with subperiosteal dissection of the paraspinal muscles is utilized [7]. Laminectomy or laminoplasty is performed from one level rostral to one level caudal to the length of the tumor [7]. Saline-moistened cottonoids are placed in the epidural space to ensure an operating field free of blood. Ultrasound before dural opening can aid in accurate localization of the tumor. Durotomy is performed in the midline rostral to the tumor and extended caudally [4, 7]. The arachnoid is preserved and opened separately. Tack-up sutures are applied to the dura for better surgical visualization [4]. An electrode is placed on the dorsal columns. Both sensory and motor evoked potentials (SEPs and MEPs) are monitored to assess the functional integrity of the spinal cord during the surgical resection.

A midline approach to the tumor is carried out. The dorsal median sulcus containing the posterior spinal vein is identified as it appears as a distinct median raphe, serving as a useful landmark [7]. The convergence of vessels on the midline is an alternative landmark. All vessels are dissected and mobilized away with care from the surgical corridor, particularly in the sulco-commissural region [4]. Distortion of the anatomy in cases of asymmetrical displacement of the cord or adherence of the tumor to the posterior columns requires the midline to be identified above and below the tumor and interpolated to the level of the tumor [4]. The spinal cord is retracted away from the lesion during resection and protected with cottonoids. The tumor is carefully dissected away from the spinal cord at its area of maximal enlargement and resected with caution [7, 8].

In cases where the tumor is located in the lumbar spine, the conus medullaris and/or the cauda equina should be protected with a cottonoid during tumor resection. The nerve fibers over the surface of the tumor are meticulously separated.

After completion of tumor resection, copious irrigation inside the resection cavity should be performed to remove all blood products. Watertight dural closure is critical for prevention of CSF leakage [4, 7]. Consideration should be given to dural grafts in order to enlarge the diameter of the thecal sac in patients with expansible lesions and local swelling [4].

CHAPTER 49

Spinal Schwannoma Resection

Mohamad Bydon*, Mohamed Macki, Joseph Lin, Jon Weingart

Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA

Keywords: Extramedullary tumor, Neurofibromatosis, Peripheral nerve sheath tumor, Schwannoma.

GENERAL ASPECTS

Intradural extramedullary tumors comprise 80% of adult spinal tumors [1 - 3]. Peripheral nerve sheath tumors and meningiomas account for the majority of these tumors and are usually benign [1]. Presenting complaints typically include radicular pain and possibly numbness or weakness, though these tumors may also be incidental findings on spinal imaging [4]. Eighty percent of meningiomas are found in the thoracic spine in female patients, usually from 40 to 60 years of age. Peripheral nerve sheath tumors are found equally in both genders at all ages and at every spinal level [1 - 5].

Neurofibromas account for 14% of peripheral nerve sheath tumors and schwannomas account for 80%; overall, peripheral nerve sheath tumors represent approximately 25% of intradural extramedullary tumors [6]. Peripheral nerve sheath tumors are associated with neurofibromatosis in 35-45% of cases, with about 90% of neurofibromatosis type 2 (NF2) patients having spinal tumors [2 - 5, 7]. Meningiomas are typically sporadic, but cases of multiple spinal meningiomas are also associated with neurofibromatosis type 2 [1].

Peripheral nerve sheath tumors typically originate within the intradural space in a dorsal nerve root and can spread to the extradural space by growth through the dural root sleeve and out the neural foramen, resulting in a dumbbell-shaped lesion. In about 10-30% of cases these tumors arise in the extradural space;

* **Address correspondence to Mohamad Bydon:** Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA; E-mail: Mbydon1@jhmi.edu

Federico Landriel and Eduardo Vecchi (Eds)

proximal growth is possible, also giving rise to a dumbbell lesion [1, 4]. Cervical spine schwannomas are most likely to have transdural growth and dumbbell appearance because intradural root segments in this region are relatively short [8]. Neurofibromas less commonly form transdural dumbbell lesions and instead typically encase nerve roots [1]. Peripheral nerve sheath tumors can be intramedullary by arising from perivascular elements that penetrate the dorsal sensory nerve roots, but this is exceedingly rare, occurring in about 1% of these tumors [8]. Meningiomas originate in arachnoid cap cells, with cervical meningiomas usually in an anterior location and thoracic meningiomas usually in a posterior location. They form extradural extensions in only about 6% of cases [1, 9, 10].

Magnetic resonance imaging (MRI) is the imaging study of choice for intradural extramedullary tumors. They are isointense to hyperintense with T1-weighted images, hyperintense with T2-weighted images, and homogenously enhance with contrast [1, 10]. Heterogenous enhancement upon contrast administration indicates a cyst, hemorrhage, or necrosis within the tumor [6].

Neurofibromas encase the dorsal nerve roots, distinguishing them from schwannomas, which displace the dorsal nerve roots and spinal cord [1, 10]. Meningiomas appear to be attached to the dura and are usually well circumscribed [1, 10].

INDICATIONS

- Radicular or dull axial pain and pain on recumbency
- Signs of increased intracranial pressure
- Motor weakness
- Sphincter dysfunction
- Sensory deficit
- Gait ataxia

CONTRAINDICATIONS

- Incidental, asymptomatic lesions that demonstrate no growth on repeat imaging

SURGICAL TECHNIQUE

General anesthesia is administered and sensory- and motor-evoked potentials (SEPs and MEPs) are monitored to ensure preservation of spinal cord function. A midline skin incision centered above the lesion is made, with adequate extent to allow retraction of muscle tissue. Laminectomy or laminotomy one level above and one below the level of the tumor should provide adequate surgical corridors. Limiting bone removal is necessary for pediatric patients, for whom a laminotomy is most appropriate; in infants, a unilateral laminectomy is the best approach. If extensive bone removal must be performed, in every fifth or sixth vertebrae a posterior arch is spared to preserve some bony structure. In all cases, care is taken to prevent damage to the spinal cord and to preserve the lateral structures of the vertebrae. In revision surgeries, removal of scar tissue should be performed with utmost care to avoid tearing of the dura or damage to adjacent neuronal structures.

After exposure, meticulous hemostasis should be obtained before opening the dura. Large moistened cottonoids are placed along the retracted musculature to prevent epidural bleeding. Compression of epidural veins is obtained with surgical strips.

A midline dural opening is performed under microscopic magnification and is extended cranially and caudally to expose the tumor in its entirety. A midline surgical approach is employed. Intraoperative ultrasonography can be a useful tool for precise localization if the tumor is not apparent from subpial coloration. If the tumor is located in a single dorsal column and is also evident on the surface of the cord, a paramedian approach may be used. Dural traction sutures are placed. The arachnoid is opened separately and is detached from the posterolateral spinal cord. Electrodes are placed for monitoring of D-wave amplitudes, which along with SEP and MEP monitoring can aid in confirming the functional integrity of the spinal cord.

Following exposure of the tumor, the plane of dissection is identified. Cauterization of the tumor capsule reduces its vascularity and size. Definition of a surgical corridor may be necessary. For cervical tumors anterior to the spinal cord, the paired denticulate ligaments should be incised on one side and lateral

CHAPTER 50

Spinal Meningioma Resection

Mohamad Bydon*, **Mohamed Macki, Allan Belzberg, Ali Bydon**

Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA

Keywords: Extramedullary tumor, Intradural, Meningioma, Spinal neoplasm.

GENERAL ASPECTS

Meningiomas have an annual incidence of 6 per 100,000 population [1]. They account for 25% of all primary spinal cord tumors [2]. Owing to the larger area of the meninges in the spinal column, intraspinal meningiomas are 4 to 5 times more common than their intracranial counterpart [3]. The meningeal overgrowths arise from the arachnoid cells and spread laterally throughout the subarachnoid space [3]. As such, these axial tumors are identified as intradural in 95% of patients, although 5% are extradural with dural origins. Upwards of 70% of all spinal meningiomas are nested in the thoracic spine, while cervical and then lumbar disease is significantly less common [3]. Moreover, the tumor has a predilection for females in their fifth decade of life, although an equal gender distribution is found in the lumbar spine [4]. According to Levy *et al*., meningiomas are likely to grow anterior to the spinal cord in the cervical spine and posteriorly in the thoracic spine [3].

Under several subtypes classified by the World Health Organization, meningiomas typically follow a benign course [5]. Slow-growing, Grade I meningothelial, or "syncytial," tumors are the most common, while Grade III, malignant papillary and rhabdoid variants have also been described [6]. Grade I tumors may exhibit calcifications or pedicle widening/ erosions on plain radiographs [7]. Historically, myelography was the initial test of choice because of the tumor's characteristic "blocks [8]". With the advent of non-diagnostic procedures, however, magnetic resonance imaging (MRI) has become the

* **Address correspondence to Mohamad Bydon:** Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA; E-mail: Mbydon1@jhmi.edu

Federico Landriel and Eduardo Vecchi (Eds)

radiographic gold standard. Seen as an intradural, extramedullary lesion in the spinal column, the tumor is isointense with the spinal cord on T1- and T2-weighted images [2, 9]. However, if a lesion is calcified on CT or hypointense on MRI, a benign course is expected [10, 11]. The differential for other intradural, extramedullary spinal cord tumors includes neurofibromas, lipomas, and rarely metastases [12].

Meningiomas may present as an incidental finding in an estimated 2 to 3% of the population, with multiple meningiomas representing 8% of the total by autopsy studies [13, 14]. These dormant, axial tumors are carefully followed with repeated imaging. When the meningioma becomes symptomatic, pain is the most common complaint followed by sensory loss, weakness, and bowel and bladder dysfunction [3]. Other studies cite spastic paraparesis as the most common symptom, reflecting the tumor's thoracic origin [14]. Regardless of the clinical presentation, symptomatic or enlarging tumors warrant surgical intervention. After a bony subtraction to reach the lesion, the surgeon attempts to perform a total excision of the meningioma and attached dura to ensure negative margins [3]. Surgical complications include postoperative cerebrospinal fluid (CSF) leaks. The follow-up period in these postoperative patients has not been well-established in the literature in so much as the recurrence rate is as low as 5-9% [14, 15].

INDICATIONS

- Dull axial pain upon recumbency
- Motor weakness, sensory disturbances, radiculopathy, loss of bowel/bladder function
- Myelopathy, gait impairment
- Signs and symptoms of increased intracranial pressure
- Radiographic evidence of an enlarging tumor
- Malignant appearance of the tumor

CONTRAINDICATIONS:

- Bleeding disorder with limited expected survival

SURGICAL TECHNIQUE

The patient is placed under general anesthesia *via* standard endotracheal intubation. The patient is then turned in the prone position on the operating room table. The posterior thoracic area is shaved, prepped, and draped in a sterile fashion. The procedure begins with a standard midline incision long enough to allow for retraction of the muscle tissue. A subperiosteal dissection of the paraspinal muscles allows for an appropriate exposure of the lamina. The spinal levels may be confirmed with intraoperative imaging. The operation proceeds with a laminectomy at least one level above and below the meningioma. As special considerations for the pediatric population are intended to protect against the increased risk of postoperative spinal instability, a laminotomy or unilateral laminectomy is better suited in patients under 18 years of age.

After an adequate exposure of the tumor, the Bovie cautery is used to achieve meticulous hemostasis. Large cottonoid applications are placed along the exposed musculature in order to protect the adjacent thecal sac. The surgery then proceeds under microscopic guidance. Using a scalpel, scissors, and Woodson dura elevator, a midline dural opening allows for the identification of the meningioma. The dura is retracted with dural traction sutures, and the arachnoid matter, meningioma and spinal cord are subsequently exposed in the surgical field. An electrode is then placed on the dorsal columns, so that intra-operative neuro-monitoring may elicit sensory and motor evoked potentials during surgical manipulation of the spinal cord.

Attention is now redirected to the meningioma. Tumor debulking is carried out with micro dissecting scissors and an ultrasonic surgical aspirator. Reduced in mass, the meningioma is carefully dissected away from the spinal cord with a bipolar cautery and ultrasonic surgical aspirator. Dural attachments are also removed with appreciable margins. The specimen is sent for pathological confirmation of the meningioma. After complete gross total resection, copious irrigation of the surgical sight removes all blood products and surgical residue. The dura is extensively cauterized, and the dural gap is re-approximated with polypropylene sutures in a water tight fashion. Evisceration of CSF is thwarted with repeated layers of fibrin sealant and synthetic collagen matrix. The surgeon

CHAPTER 51

Minimally Invasive Thoracic Intradural Extramedullary Tumor Resection

Albert P. Wong*, **Samer G. Zammar, Zachary A. Smith, Richard G. Fessler**

Department of Neurosurgery, Rush University Medical Center, Chicago, Illinois, USA

Northwestern University, Department of Neurological Surgery, Chicago, IL, USA

Keywords: Intradural extramedullary tumor, Meningioma, Minimally invasive, Thoracic tumor video.

CASE PRESENTATION

A 56 year-old right handed female with several months' history of upper back pain radiating to the left side of the chest is presented. She also describes having bilateral lower extremity paresthesias and recent balance difficulties. She denies any weakness in her extremities, or difficulties in control of bladder or bowels.

On physical examination, the patient is strong throughout without sensory deficits. Her reflexes are 3+ in bilateral lower extremities, left greater than right foot clonus, and presence of bilateral Babinski's, Hoffman's sign is not present.

IMAGING STUDIES

An MRI of the thoracic spine with and without contrast demonstrates an avidly enhancing mass ventral to the spinal cord at T4. The lesion is intradural, extramedullary with compression and displacement of the spinal cord dorsally and to the right. There is no evidence of spinal cord edema on MRI (Fig. **1**).

* **Address correspondence to Albert P. Wong:** Department of Neurosurgery, Rush University Medical Center, Chicago, Illinois, USA; E-mail: a-wong@fsm.northwestern.edu

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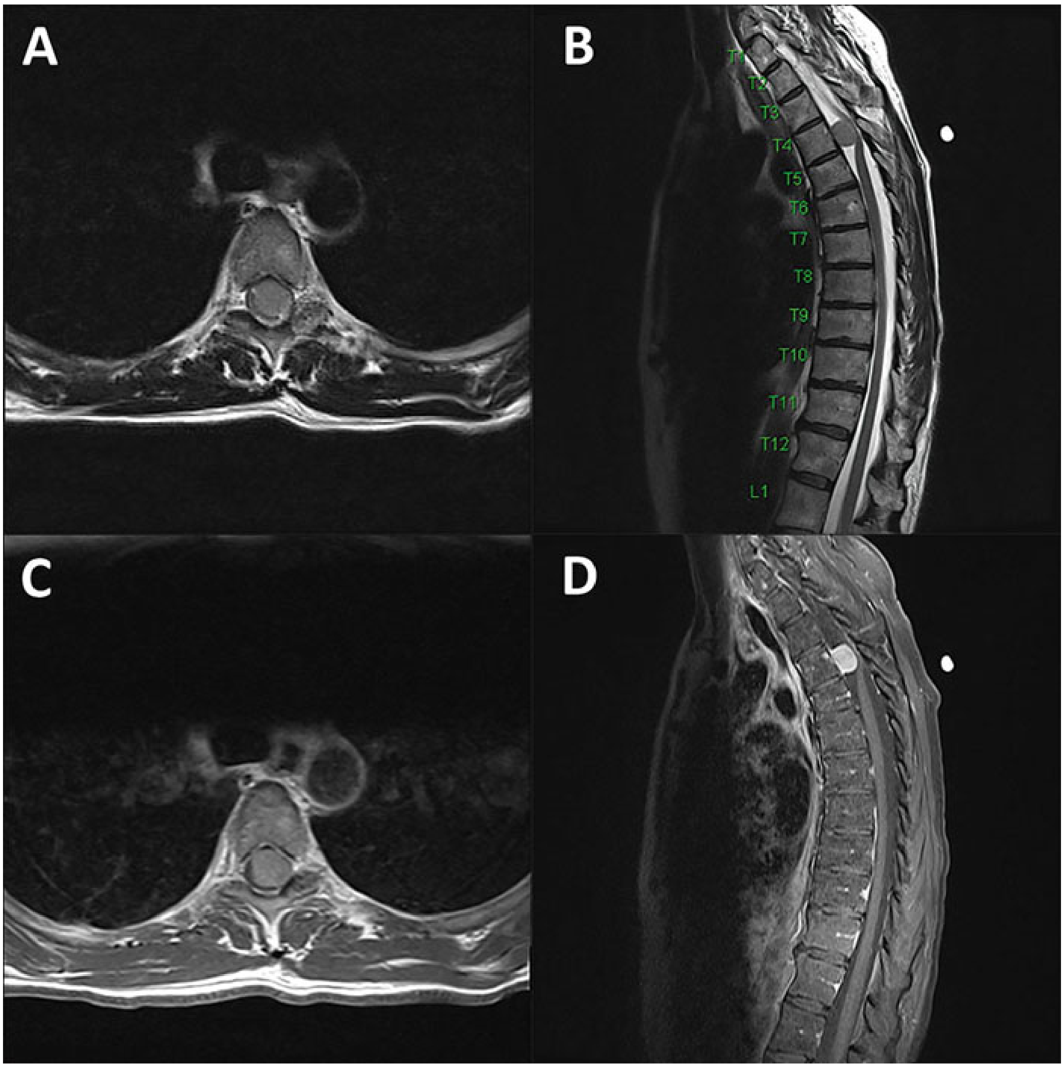

Fig. (1). A and B shows T2 axial MRI and T2 sagittal MRI of the thoracic spine demonstrating an intradural extramedullary mass ventral to the spinal cord. C and D demonstrates T1 axial and T1 sagittal MRI with contrast shows a homogenously enhancing mass with a thickened "dural tail". The enhancing mass compresses and displaces the spinal cord dorsally and to the right.

SURGICAL TECHNIQUE

Positioning

The patient is secured in a three-point Mayfield head-holder and turned prone onto an open Jackson operating table with the arms tucked at the side. All bony prominences and vulnerable pressure points are padded. The neck is placed in a neutral position and the head of the table is placed in reverse Trendelenburg to decrease venous hypertension and epidural bleeding. The skin is shaved and cleaned with alcohol. The midline is marked with a skin marker over the prominent spinous processes and a parallel skin incision line is drawn 1.5 cm ipsilateral (left) of the midline (Fig. **2**).

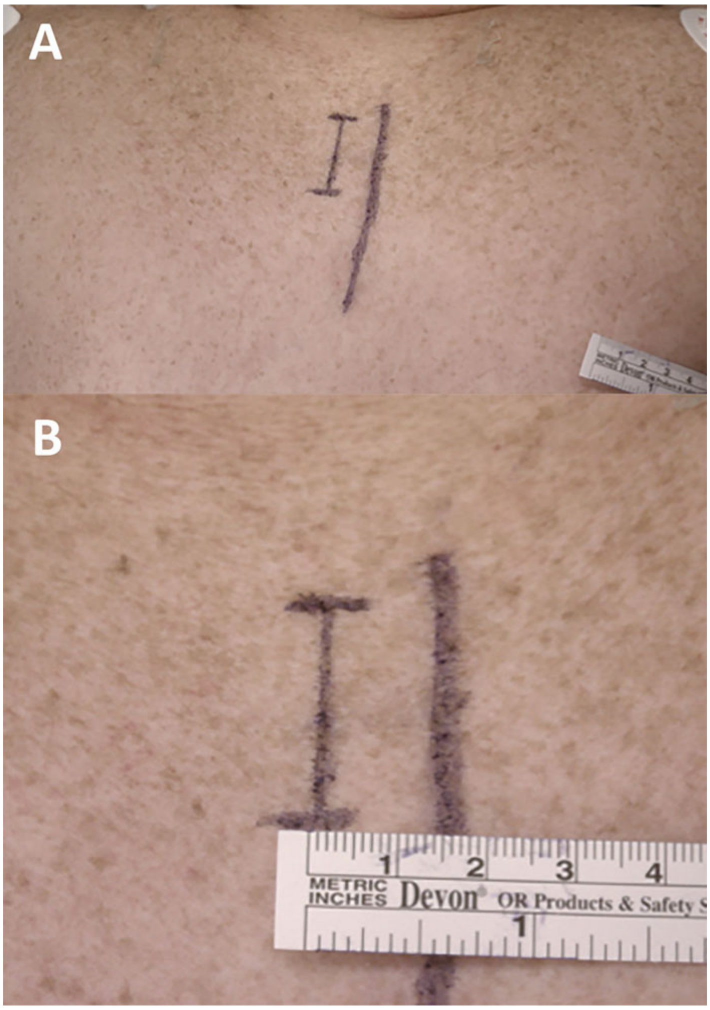

Fig. (2). A. The midline superficial to the spinous processes is highlighted with a skin marker. A twenty-six millimeter line is drawn ipsilateral to the lesion. **B.** Magnified view of the incision drawn fifteen millimeters lateral to the midline.

CHAPTER 52

Sacral Tumors Resection

Mohamed Macki*, Mohamad Bydon, Jean-Paul Wolinsky, Ziya Gokaslan

Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA

Keywords: Lumbopelvic reconstruction, Sacral tumor, Sacrectomy video, Sacrum.

GENERAL ASPECTS

Primary neoplasms of the sacrum are rare, complex tumors that account for 1-7% of spinal tumors [1, 2]. They are usually discovered only when become quite large due to the gradual onset of nonspecific symptoms, typically pain and neurologic deficits [3]. Primary sacral tumors are most often chordomas (40% of malignant cases, usually diagnosed over age 40 and in males), chondrosarcomas (5% of malignant cases, usually diagnosed ages 30-60 and roughly equally in both genders), and giant cell tumors (the most common benign cause) [2 - 5]. Because of the size and extent that sacral tumors often achieve before diagnosis, surgical excision can be difficult and will not prevent recurrence if margins are positive [3,6].

En bloc resection is the standard of care, providing the best chance for tumor-free survival [2,6]. Tumors involving the S1 and S2 levels tend to have more favorable prognoses because *en bloc* resection is more feasible [7]. Such operations are complex, demanding, and have significant effects on quality of life. Complications include neurological deficits due to nerve root sacrifice, including bladder, bowel, and sexual dysfunction, as well as biomechanical effects due to destabilization of the pelvic ring, particularly ambulatory impairment. Rehabilitation can restore some neurological function and partial sacrectomy will preserve pelvic stability [7].

* **Correspondence to Mohamed Macki:** Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, USA; E-mail: mmacki1@jhmi.edu

Federico Landriel and Eduardo Vecchi (Eds)

Techniques are evolving in treating sacral tumors with sacrectomy and reconstruction of the pelvic ring. Shikata *et al*. performed one of the earliest such operations in 1988, followed by Tomita and Tsuchiya using similar procedures in 1990; these cases used two stages with an anterior approach followed by a posterior approach [8, 9]. In 1997, Gokaslan *et al*. reported a more stable method of reconstruction using the Galveston L-rod technique [7]. In 2008, McLoughlin *et al.* described a total sacrectomy in which the tumor was resected *en bloc* in a single stage procedure through a posterior approach [6].

Partial sacrectomy is a more sparing procedure that can achieve negative margins in appropriate cases but is still complicated by the involvement of skeletal, visceral, neurological, and vascular structures in the pelvis [10]. Pelvic reconstruction for a partial sacrectomy requires technical flexibility because of the variability in tissue excision between different cases. Outcomes-based recommendations for decisions on reconstruction remain nascent, though resection volume has been found to be an important determinant in choice of technique [11].

INDICATIONS

- Benign sacral tumors, such as giant cell tumors, osteochondroma, and osteoid osteomas, with clinically significant mass effect.
- Malignant non-metastatic primary sacral tumors, such as chordoma, Ewing's sarcoma, osteosarcoma, and primitive neuroepithelial tumor.

CONTRAINDICATIONS

- Metastatic tumors, as the goal of surgery for sacral tumors is disease-free survival through local control [2 ,7, 10].
- Quality of life considerations due to neurological and biomechanical impairment.

SURGICAL TECHNIQUE (PARTIAL SACRECTOMY)

An adapted Kraske approach is used to gain access to the tumor. A midline incision is made over the sacrum and coccyx. The anococcygeal raphe is divided and the gluteus maximus muscle is dissected to expose the sacrum and coccyx.

The levator ani muscles are freed from the coccyx, which may also be removed. The lateral distal sacrum and Waldeyer's fascia are identified. The muscular and ligamentous attachments to the sacrum are detached, creating access between the mesorectum and the presacral component of the lesion. The resulting corridor along the entire ventral surface of the sacrum allows resection of any sacral tumor, provided that the rectum is carefully protected.

Subperiosteal dissection exposes the posterior aspect of the S2 and S3 vertebrae and the left and right greater sciatic notches. Laminectomy of S2 and S3 exposes the thecal sac and the exiting S2 and S3 nerve roots. The S2 and S3 nerves are preserved, while the distal thecal sac is ligated and cauterized. The distal thecal sac is then sacrificed along with the S4 and S5 nerve roots. The epidural venous plexus is cauterized to provide homeostasis for the subsequent osteotomies.

The S3 nerve roots are carefully identified all the way to their foramina to ensure their protection during the osteotomy steps. Two lateral osteotomies between the left and right S3 foramina and their ipsilateral sciatic notches are performed, followed by detachment of deep gluteal and pelvic muscles and ligaments as necessary for resection of the tumor. Then, a transverse osteotomy between the S3 foramina is performed to allow mobilization and subsequent amputation of the sacrum caudal to the S3 level, using the established corridor on the ventral aspect of the sacrum to protect the rectum. Bleeding from the osteotomies is controlled with bone wax. While the S3 nerve root is carefully preserved, the S4 and S5 nerve roots and any remaining soft tissue attachments are severed, freeing the tumor, which can thus be removed *en bloc*. Finally, a plastic surgery team reconstructs soft tissue defects by utilizing a gluteus maximus flap and AlloDerm®.

COMPLICATIONS

- Hemorrhage due to injury of the internal iliac, iliolumbar, and median sacral vessels, which may require a laparotomy.
- Injury to the rectum.
- Wound infection or dehiscence.
- Sensorimotor, bowel, bladder, and sexual dysfunction.

CHAPTER 53

Thoracolumbar Extradural Arachnoid Cyst Surgery

Federico Landriel*, Eduardo Vecchi, Santiago Hem, Damian Bendersky, Ezequiel Goldschmidt

Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina

Keywords: Arachnoid cyst technique, Arachnoid cyst video, Extradural arachnoid cyst, Meningeal cyst resection.

GENERAL ASPECTS

Spinal extradural arachnoid cyst (SEAC) is a rare herniation of arachnoid membrane through a dural defect that may cause compressive radiculo-myelopathy symptoms and enlarging of the spinal canal bone. They are more frequently located at the thoracic spine, commonly in a posterior position with extension to a neural foramen. Its etiology is still unclear and can be either congenital or acquired [1]. They can be enlarged as a result of pressure changing in the cerebrospinal fluid (CSF) during exercise and Valsalva maneuvers, as there is micro-communication between the cysts and subarachnoid space that may act as a one-way valve mechanism [1, 2].

INDICATIONS

- Pain or weakness as a result of radiculo-myelopathy
- Lower limbs numbness
- Low back pain

SURGICAL TECHNIQUE

Under general anesthesia, somatosensory-evoked potentials and motor-evoked

* **Correspondence to Federico Landriel:** Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina; E-mail: fedelandriel@gmail.com

Federico Landriel and Eduardo Vecchi (Eds)

potentials baseline signals are monitored. The patient is placed in prone position with rolls under the chest and iliac crests. Lateral fluoroscopy is used to confirm the surgical level. For posterolateral located cyst a unilateral subperiosteal approach is made exposing the right side of the spinous process, laminas and the medial aspect of the facet joints. Care should be taken to preserve the supra and interspinous ligaments. A self-retaining retractor is applied and the surgical level is re-confirmed with a needle and lateral fluoroscopy.

A right hemilaminectomy is performed using Kerrison rongeurs or a high-speed drill. Under microscopic magnification the pulsatile extradural cyst is identified and exposed (Fig. **1**). Using a nerve hook, blunt careful dissection is made between the cyst wall and the surrounding structures. The dural connection or stalk is found usually in the axillar portion of a nerve root (Fig. **2**). The dural stalk is dissected and closed with 3-0 silk suture ligation or repaired with prolene 5-0. After cyst occlusion the remnant sac is gently pulled and dissected from the surrounding structures. The cyst is opened and clear liquid flows. Once the cyst deflates, with gentle maneuvers, the remnant arachnoid membrane is completely removed (Fig. **3**). Valsalva maneuver is performed to demonstrate absence of CSF leakage. Dural sealer could be used to reinforce watertight occlusion. The wound is closed as usual. The patient is commonly discharged on the second postoperative day.

COMPLICATIONS

- Cerebrospinal fluid leak
- Epidural hematoma
- Wound infection
- Nerve root/spinal cord injury
- Postoperative kyphosis/malalignment as a result of a wider than necessary bone remotion

POSTOPERATIVE MANAGEMENT

The patient is encouraged to ambulate as soon as post-anesthesia recovery permits. An opioid/acetaminophen combination, mild muscle relaxant, and analgesics are prescribed. The patients are usually discharged home within 48 hours after their surgical procedure and are instructed to begin general motion with a progressive exercise program. Return to work and sports are restored at 1-2 months postoperative.

OUTCOMES

Surgical management remains the gold standard treatment for patient with signs and symptoms due to cyst expansion and neuro-structures compression [3]. Surgical options range from complete resection of the cyst and defect closure through laminectomy or laminoplasty of all the affected levels, to a partial resection of the cyst with or without closure of the communication through selective laminectomy. Funao *et al.* [4] report a significant difference in the mean postoperative kyphotic angle between patients treated by total resection of the cyst (9.7°) and those treated by closure of the dural defect without cyst resection through selective laminectomy (2.2°) ($P< .05$). The optimal surgical approach should be tailored to each patient according to the size and location of the cyst. Significantly worse outcomes were observed in patients whose symptoms had persisted for more than 1 year and in those with a cyst size of more than 5 vertebrae [5]. Patients with a short history of symptoms are more likely to benefit from surgery [6, 7].

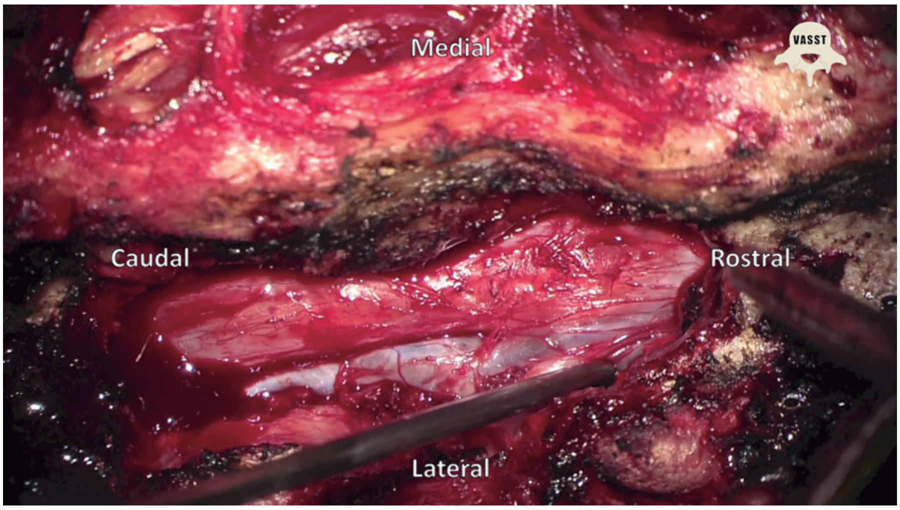

Fig. (1). Intraoperative photograph shows the anterolateral extradural cyst exposure.

CHAPTER 54

Lumbar Synovial Cyst Surgery

Federico Landriel*, Eduardo Vecchi, Santiago Hem, Sofia Beltrame, Jorge Rasmussen

Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina

Keywords: Synovial cyst technique, Synovial cyst surgery, Synovial cyst video.

GENERAL ASPECTS

Synovial cysts arise from the synovium of the adjacent facet joint and they are commonly found at L4-L5 level [1, 2]. They can cause painful radiculopathy, back pain and cauda equine syndrome. There is a strong correlation between synovial cyst and spondylolisthesis at the same level, the vast majority Meyerding Grade 1 [1]. Spinal fusion is indicated when preoperative or postoperative instability is confirmed [3]. Minimally invasive techniques may be considered.

INDICATIONS

- Symptomatic lumbar synovial cyst
    - Radiculopathy (after failed conservative therapy)
    - Motor weakness
    - Neurogenic claudication
    - Cauda equina or conus syndrome
- Instability (with fusion/instrumentation)

SURGICAL TECHNIQUE

Under general anesthesia, somatosensory-evoked potentials and motor-evoked potentials baseline signals are monitored. The patient is placed in prone position on a Wilson frame and a radiolucent table. Lateral fluoroscopy is used to confirm the surgical level. The patient is draped in a sterile fashion. A 3-4 cm midline skin

* **Address correspondence to Federico Landriel:** Department of Neurosurgery, Hospital Italiano, Buenos Aires, Argentina; E-mail: fedelandriel@gmail.com

incision is made for a single level exposure. A unilateral subperiosteal approach is made exposing the right side of the spinous process, laminas and the medial aspect of the facet joint. A self-retaining retractor is applied. The level is re-confirmed with a needle and lateral fluoroscopy.

The interlaminar space is identified and cleared of overlying soft tissue with monopolar cautery. Depending on synovial cyst size and location, a hemilaminectomy or laminectomy is performed using Kerrison rongeurs or a high-speed drill. The ligamentum flavum is superficially incised with a No. 15 blade. A dissector is used to split the ligamentum fibers and enter the canal. A limited medial facetectomy is performed (Fig. **1**). The flavum ligament is removed from the lateral and foraminal regions.

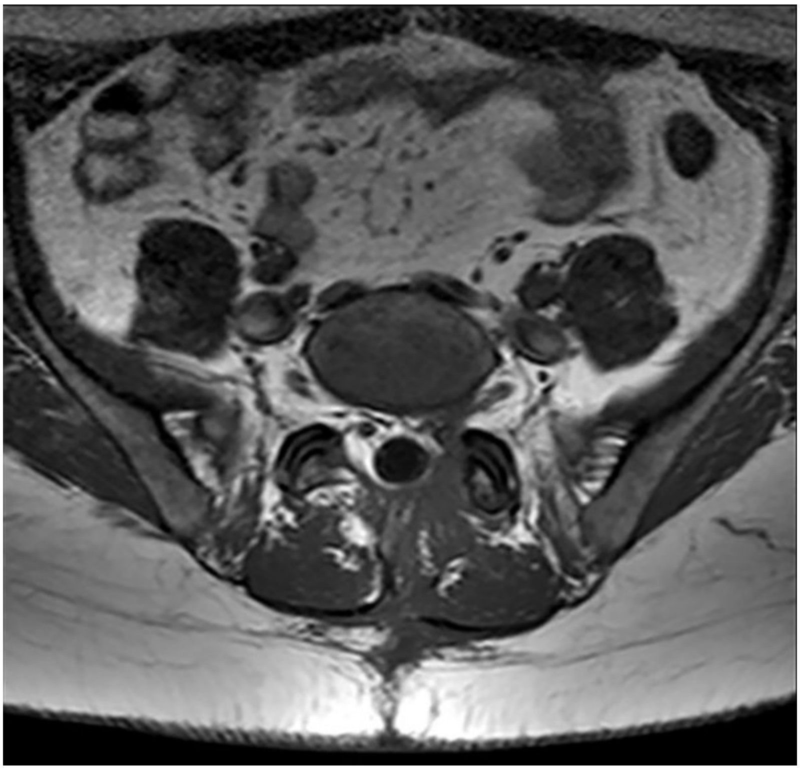

Fig. (1). Pre and postoperative axial MRI demonstrate left L5-S1 facetectomy and complete cyst remotion.

The cyst is identified and dissected from the thecal sac and nerve root (Fig. **2**). If a wider facetectomy is needed in order to completely remove the synovial cyst, stabilization should be considered. If a cleavage plane is found the cyst may be entirely removed in one piece. For large cyst, strongly adherent to the dura or nerve root, piecemeal remotion is advisable in order to avoid unintentional durotomy. The facet joint is curetted to remove remaining cyst material if present. Hemostasis is archived. The surgical field is irrigated with physiological saline solution. Valsalva maneuver is performed to demonstrate absence of CSF leakage. The wound is closed as usual; skin is closed with a subcutaneous running 4.0 monocryl suture. Usually the patient is discharged on the second postoperative day.

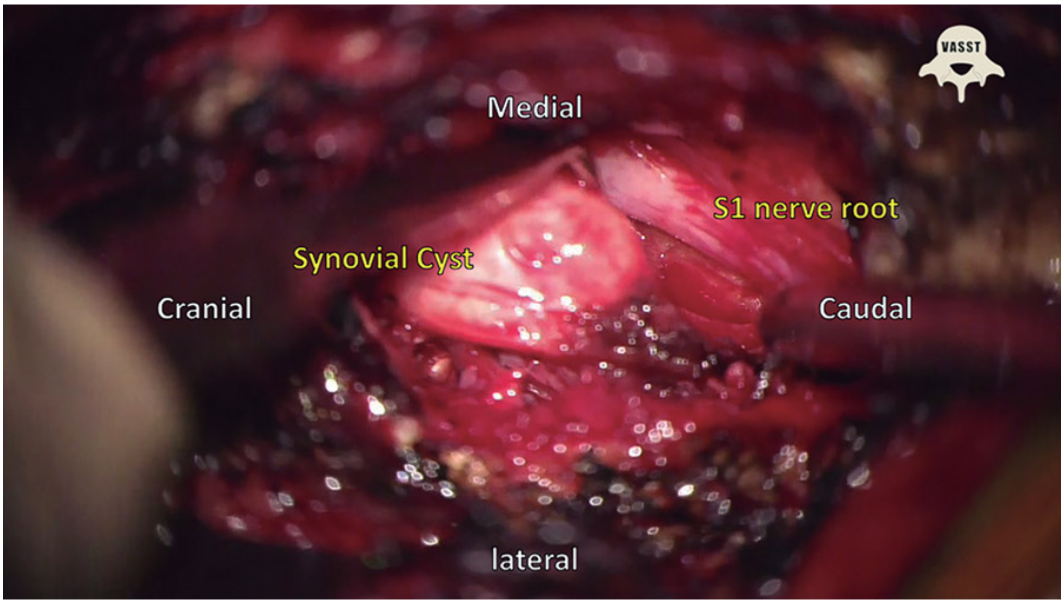

Fig. (2). Intraoperative photograph shows synovial cyst and left L5 nerve root.

COMPLICATIONS

- Wound infection
- Nerve root injury
- Cerebrospinal fluid leak
- Epidural hematoma
- Synovial cyst recurrence
- Postoperative instability as a result of a wider than necessary bone remotion

CHAPTER 55

Treatment of Tarlov (Perineural) Cysts by Open or Endoscopic Assisted Exclusion

Juan José Mezzadri*, Santiago González Abbati, Pablo Jalón, Paula Ypa, Federico Fernández Molina

Department of Neurosurgery, University Hospital "José de San Martín", University of Buenos Aires, Argentina

Keywords: Lumbar Pain, Perineural Cyst, Spinal Endoscopy, Tarlov Cyst Video.

INDICATIONS AND CONTRAINDICATIONS

Tarlov or perineural cysts (PC) are sacs filled with cerebrospinal fluid (CSF), distally to the nerve root ganglion. A variable communication with the spinal subarachnoid space makes them filled with CSF. This raises its hydrostatic pressure, becoming symptomatic by compressing nearby structures [1, 2].

PCs have a prevalence of 1.5% and only 13% of them are symptomatic [3]. Pain is the most frequent symptom, usually presenting as lumbalgia, sciatica and/or coccygodynia. Perineal pain located in the vagina and/or anus is more characteristic of PCs; it may be associated with genital paresthesias. In the great presacral cysts, the pain can be abdominal. Frequently, patients can also have dysfunctional bladder and/or rectal symptoms: tenesmus, frequency, urgency and/or incontinence. Also, sexual dysfunctions as dyspareunia or infertility can be present.

Surgery is indicated when PC are symptomatic and patient´s complaints severely disturb their daily living. There are no formal contraindications.

SURGICAL TECHNIQUE

In order to standardize the surgical treatment, PCs are classified into two types

* **Address correspondence to Juan José Mezzadri:** Department of Neurosurgery, University Hospital "José de San Martín", University of Buenos Aires, Argentine; E-mail: jjmezzadri@gmail.com

Federico Landriel and Eduardo Vecchi (Eds)

according to their number, location and size viewed on the magnetic resonance images (MRI): midline cysts (usually single, with a size ≥ 4 cm) or lateral cysts (usually multiple, with a size of 2-3 cm). These characteristics determine the most suitable surgical procedure: endoscopic assisted surgery (EAS) [4] or non-endoscopic assisted surgery (NEAS).

Endoscopic Assisted Surgery

In the midline cysts, a 2-3 cm skin incision and a small sacral opening over the caudal portion of the cyst is performed. This allows the introduction of a rigid endoscope with a 0° optic through the lower cyst pole. Without delay, a controlled and complete aspiration of the CSF from inside the cyst is performed in order to work with the endoscope in a dry field. Then, with a 30° - 45° inclination and through the longitudinal axis of the cyst, the communication with the spinal subarachnoid space is searched (Fig. **1**).

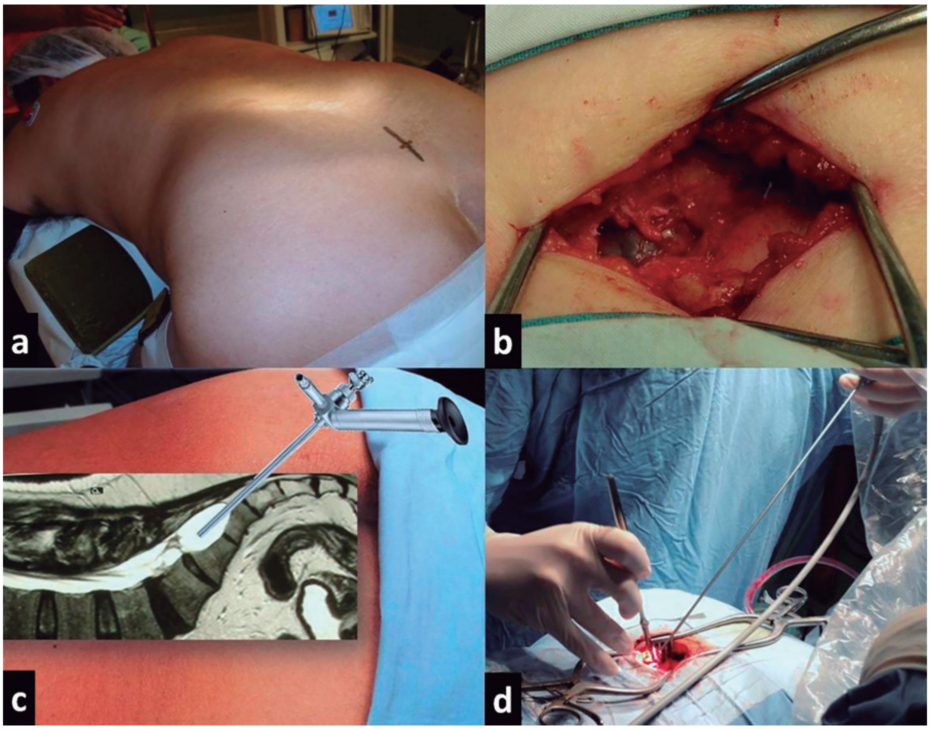

Fig. (1). (a) 3 cm skin incision at the level of the caudal portion of the cyst, **(b)** small sacral bone window and visualization of the pole of the cyst, **(c)** and **(d)** entry point and direction of a rigid endoscope.

In some cases, this communication is difficult to see at first glance because no CSF is seen to enter into the cyst. So, the anesthesiologist performs a Valsalva maneuver. Then, the CSF enters easily into the de cyst, allowing the surgeon to see the communication. Once individualized, it is plugged with fat tissue, muscle, gelfoam and fibrin glue, completing the exclusion of the cyst.

As the midline cysts are bigger, there is enough space to maneuver with the endoscope and, with a proper inclination it is possible to find the communication with the spinal subarachnoid space. In addition, as they are single, it is enough to perform only one small opening over the skin and bone, being much less invasive.

Non-Endoscopic Assisted Surgery

The lateral cysts are exposed through a sacral laminectomy and then opened. Secondly, they are excluded by plugging their spinal CSF communication with fat tissue, muscle, gelfoam and fibrin glue.

As the lateral cysts are smaller, it would have been impossible to have enough space to mobilize the endoscope inside them. Then, the view of the communication with the spinal subarachnoid space would have been difficult. In addition, as lateral PC are multiple, it would have been necessary to perform several entry points through the skin and bone to introduce the endoscope into each cyst separately. Thus, we perform a sacral laminectomy that exposes all the cysts simultaneously.

COMPLICATIONS

In the EAS cases there were no complications. In the NEAS cases we had a CSF fistula in 5 of the first 7 cases [4].

POSTOPERATIVE MANAGEMENT

Postoperatively, all cases have an external lumbar drainage during five days in order to assure the stability of the plugging, by avoiding the effects of the CSF column hydrostatic pressure over the plug.

CHAPTER 56

Surgical Treatment of Spinal Dural Arteriovenous Fistulas

Amr Mouminah*, **Alexander Ropper** , **Rose Du**

Department of Neurosurgery, Brigham and Women's Hospital, Harvard Medical School. Boston, MA, USA

Keywords: Spinal fistula technique, Spinal A-V surgery, Spinal AV fistula video.

INDICATIONS AND CONTRAINDICATIONS

Spinal dural arteriovenous fistulas (sDAVF) are treatable with excellent outcomes. Patients presenting with a wide range of symptoms may warrant treatment either by using open microsurgical or endovascular techniques. Surgery is safe and effective in most cases with successful treatment as high as 98% [1]. It is specifically indicated in patients with lesions not amenable to embolization due to technical or angioarchitectural complexity that prevents delivery of embolic material to the proximal draining vein or in lesions where the feeding radicular artery is the artery of Adamkiewicz, which feeds the anterior spinal artery [2]. Refractory cases and those patients considered to be at high risk for embolization (such as those with severe atherosclerotic diseases) should also be treated surgically [3].

There is no specific contraindication for surgical treatment of spinal dural arteriovenous fistula unless other severe medical comorbidities exist and the patient is not a good surgical candidate in general.

SURGICAL TECHNIQUE

The main treatment goal of sDAVF is elimination of venous congestion of the

* **Address correspondence to Amr Mouminah:** Department of Neurosurgery, Brigham and Women's Hospital, Harvard Medical School. Boston, MA, USA; Email: amr.mouminah@yahoo.com

Federico Landriel and Eduardo Vecchi (Eds)

spinal cord. The venous congestion with resulting venous hypertension, ischemia and edema is believed to be the main cause of myelopathy. Elimination of venous hypertension is achieved by ligation of the fistula at the transition point from artery to vein (*i.e.* the fistula point).

Preoperatively, imaging studies, especially ***digital subtraction angiography (DSA)*** must be reviewed carefully to identify the extent of the lesion and determine the location of the feeding artery (Figs. **1A** and **1B**). Care must be taken to evaluate for multiple feeding arteries, although generally, there is a single feeder. Some surgeons strongly advocate the use of intraoperative monitoring to monitor the spinal cord function during surgery, but this has not been universally adopted.

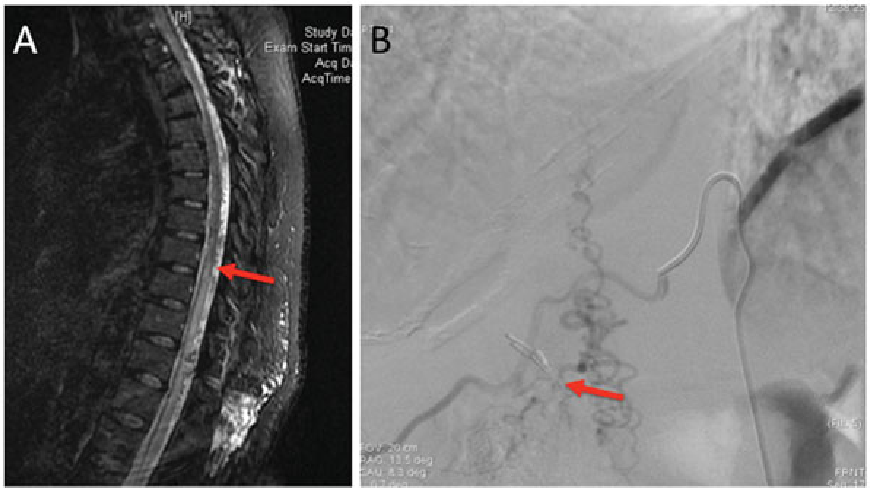

Fig. (1). (A) Preoperative MRI STIR sequence demonstrates intramedullary T2 hyperintensity of the spinal cord and intradural extramedullary flow voids (arrow) along the dorsal aspect of the spinal cord. **(B)** Preoperative spinal angiogram, right T11 injection (AP view), demonstrates the dural arteriovenous fistula (arrow at fistula)

Patients are positioned prone on a Wilson frame or chest rolls. Positioning should be performed so as to avoid increasing intra-abdominal pressure. The spinal level is verified by plain film radiography or with C-arm fluoroscopy. A standard laminectomy approach is performed. Ideally, the laminectomy is performed by removing the lamina, spinous processes and ligamentum flavum without causing significant disruption of the facet joints, so as to avoid post-laminectomy kyphosis or instability. Sufficient bony removal must be completed to expose the nerve root of interest. The dura and accompanying nerve root sleeve are carefully examined before a midline durotomy is performed. Dural tack-up sutures are placed to improve hemostasis and visualization. The arachnoid dissection is then carefully completed under the microscope with the use of microdissectors and microscissors. Following this, the origin of the arterialized medullary vein is identified at the site of the dural penetration of the nerve root (Figs. **2A** and **2B**). The vein is carefully dissected away from the surrounding nerve root. Obliteration of the fistula at the arteriovenous connection is completed by coagulation with bipolar forceps followed by division with microscissors. Feeding arteries identified along the dura or nerve root sleeve may be coagulated although, that is not necessary.

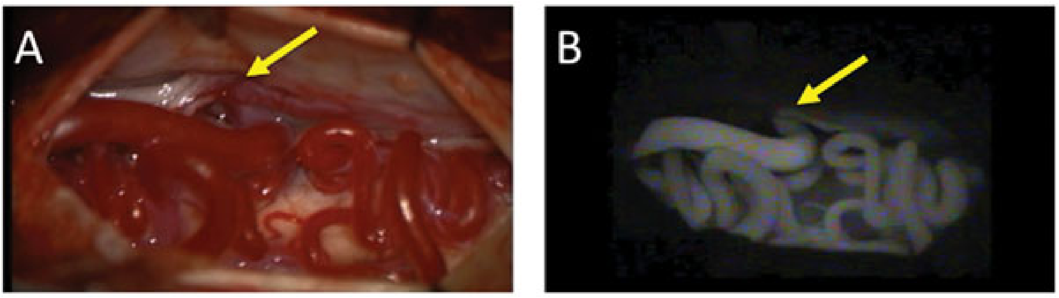

Fig. (2). (A) Intraoperative photo of the fistula and the arterialized draining vein at its dural entry point (arrow). **(B)** Indocyanine green angiography demonstrates early shunting into the arterialized draining vein.

Following division of the fistula point, the dorsal spinal veins will show decreased turgor and may no longer appear arterialized (Fig. **3A**). Under direct microscopic visualization using the appropriate optical filter, indocyanine green (ICG) fluorescent dye is injected into a peripheral vein to look for any remaining early venous drainage which may occur if there are feeding arteries at other locations (Fig. **3B**). The ICG technology allows easy, real-time, intraoperative angiographic evaluation without formal digital subtraction angiography. However, a formal spinal angiogram should still be performed postoperatively. The dura is closed in a watertight fashion with a 6-0 permanent suture. The lamina can be replaced with a laminoplasty kit to attempt to reconstruct some of the posterior elements, however, this is not required and depends on the surgeon's preference. Finally, the

CHAPTER 57

Surgery of Intramedullary Cavernous Malformations

Jan-Karl Burkhardt*, **Jorn Fierstra, Johannes Sarnthein , Oliver Bozinov**

Department of Neurosurgery, University Hospital Zurich, Switzerland

Keywords: Intramedullary tumor, Intraoperative electrophysiology, Minimally invasive surgery, Spinal cavernoma video.

INDICATIONS AND CONTRAINDICATIONS

Intramedullary cavernous malformations (IMCM) are rare spinal lesions with only about 200 cases described in the present literature [1 - 4]. The intraspinal location accounts for approximately 5% of all cavernous malformations in the central nervous system and for about 5%–12% of all spinal cord vascular lesions [1].

Compared to the intracerebral location, IMCMs are more likely to present with acute onset of neurological deficits, chronic progressive decline in neurological function (such as progressive myelopathy) or pain caused by subarachnoid hemorrhage and arachnoiditis [1, 3]. The most definitive treatment of symptomatic intramedullary IMCMs consists of total microsurgical excision to improve neurological deficits and/or to prevent re-bleeding. Conservative treatment without surgery is not recommended for symptomatic lesions. Even in incidental lesions, conservative clinical management rather than surgery is recommended; however the role of surgery for such lesions remains controversial.

The risk of bleeding, which has been reported to be 1.4%–4.5% per year in the literature, as well as the stable or improved functional status in 92% of patients needs to be kept in mind during the decision making process and favors the recommendation for surgery [1 - 4].

* **Address correspondence to Jan-Karl Burkhardt:** Department of Neurosurgery, University Hospital Zurich, Switzerland; Email: Jan-Karl.Burkhardt@usz.ch

Federico Landriel and Eduardo Vecchi (Eds)

SURGICAL TECHNIQUE

The surgical technique is based on the microsurgical resection of the IMCM lesion, ideally with the aid of intraoperative imaging modalities such as ultrasound and intraoperative neurophysiological monitoring. As shown in our video, patients are usually positioned in a prone position and the spinal region of interest is marked under visual control of x-ray beams before skin incision. A single or multilevel hemilaminectomy/laminectomy or laminoplasty can be performed depending on the location and size of the lesion [1]. After opening of the dura and arachnoid, the location of the IMCM lesion is important for defining the appropriate site of myelotomy. For this purpose intraoperative ultrasound is useful - before opening the dura - to localize the IMCM lesion and to also perform resection control after removal of the lesion for complete resection [4]. If the lesion is visible at the dorsal surface of the spinal cord, dissection is started directly over the lesion. In case of deep located lesions myelotomy over an area of discoloration or a midline myelotomy approach is used [5]. Another possibility is a lateral approach directly below the exit of a nerve. During resection, intraoperative neurophysiological monitoring (IONM) is recommended to preserve sensory and motor function [6, 7]. Since IONM is affected by inhalational anesthetic agents, total intravenous anesthesia is preferred. Continuous monitoring of sensory function is based on somatosensory evoked potentials (SEPs) with stimulation of tibialis and medianus nerve at the limbs and recording on the scalp. Continuous monitoring of motor function is performed through motor evoked potentials (MEPs) with electrical stimulation at the scalp and recording of responses at limb target muscles; catheter electrodes permit to record also from the spinal cord’s epi- or subdural space. Furthermore, nerves in the surgical field can be identified by direct stimulation with a handheld probe.

Also, the dissection technique and operative strategy may influence the patient´s outcome of IMCM. As shown in our video the alteration of very thin bipolar forceps and microscissors use to sharply disconnect tiny feeders and draining vessels to the lesion is important to avoid the injury of normal spinal cord tissue. In case of large IMCM lesions, gradual removal is required [5].

COMPLICATIONS

Surgical complications may occur depending on the localization of the lesion. The use of intraoperative imaging (ultrasound) and neurophysiological monitoring can be useful to decrease surgically related neurological complications. It is also important to achieve a complete resection of the IMCM, since partial resection can cause rebleeding and development of new neurological deficits. However, only the cavernomas should be removed and not the perilesional hemosiderin infiltrated tissue as recommended in non-eloquent cranial lesions for epilepsy treatment. The study by Mitha *et al.* reported the largest case series (n= 80 patients) with a 25-year experience of IMCM surgery. Reported immediate postoperative complications included DVT in 2.5%, CSF leak in 2.5% and serous fluid collection in 1.3%. Delayed complications including kyphosis, tethered cord and spinal stenosis were present in 6.4%, 4.8% and 3.2% of the cases [1].

POSTOPERATIVE MANAGEMENT

Standard postoperative clinical management after spinal dural access includes bed rest for 48 hours after surgery and support from an interdisciplinary team, including physiotherapy and ergo therapy, to increase mobilization thereafter. In our institution we recommend a spinal MR follow-up 3 months postoperative. We would like to emphasize again that the goal of surgical removal of an IMCM lesion is to prevent further neurological decline. In this light, we do not anticipate a fast neurological improvement in the acute postoperative setting in case of preoperative neurological deficits. It has been reported by others that in 23% of cases neurological improvement may still be seen 5 years after surgery [1].

Lastly, instability of the spine may occur after laminectomy during these surgeries. This may lead to kyphosis. Postoperative care, especially physiotherapy, should aim to minimize this risk. Ideally, these circumstances are considered at the choice of the approach and hemi laminectomy or laminoplasty is selected whenever possible.

OUTCOMES

Previous studies reported a permanent improvement or stable disease in surgically

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GLOSSARY

AAD	= Atlantoaxial Dislocation
AAL	= Anterior Longitudinal Ligament
ACDF	= Anterior Cervical Discectomy with Fusion
AICG	= Autogenous Iliac Crest Bone Graft
ALIF	= Anterior Lumbar Interbody Fusion
AP	= Anteroposterior
CBT	= Cortical Bone Trajectory
COR	= Center of Rotation
CSF	= Cerebrospinal Fluid
CT	= Computed Tomography
CTE	= Costotransversectomy
CUSA	= Cavitron Ultrasonic Aspirator
DDD	= Degenerative Disc Disease
DLIF	= Direct Lateral Interbody Fusion
DR	= Disc Rongeur
DSA	= *Digital Subtraction Angiography*
DVBD	= Direct Vertebral Body Derotation
DVT	= Deep Vein Thrombosis
EAF	= Endoscopic Anterior Foraminotomy
EAS	= Endoscopic Assisted Surgery
ECD	= Endoscopic Chiari Decompression
EMG	= Electromyogram
FBBS	= Failed Back Surgery Syndrome
FDA	= Food and Drug Administration
HB	= Hemangioblastomas
HNP	= Herniated Nucleous Pulposus
IAP	= Inferior Articular Process
ICG	= Indocyanine Green
ICU	= Intensive Care Unit
IMCM	= Intramedullary Cavernous Malformations
IOM	= Intraoperative Neuromonitoring
IONM	**correspondence to Jan-Karl Burkhardt:**

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ioUS = Intraoperative ultrasound
IVC = Inferior Ven Cava
K = Kirschner
KP = Kerrison Punch
LECA = Lateral Extracavitary Approach
LLIF = Lateral Lumbar Interbody Fusion
LLS = Lumbar Spinal Stenosis
LPDS = Lumbar Posterior Dynamic Stabilization
MAL = Mamillo-Accessory Ligament
MAP = Mean Arterial Pressure
MAST = Minimal Access Spinal Technologies
MEP = Motor-Evoked Potential
MI-PCF = Minimally Invasive Posterior Cervical Foraminotomy
MIDLF = Midline Lumbar Fusion
MIS = Minimally Invasive Surgery
MRI = Magnetic Resonance Imaging
NEAS = Non-Endoscopic Assisted Surgery
NF2 = Neurofibromatosis Type 2
NR = Nerve Root
NSAID = Nonsteroidal Anti-Inflammatory Drug
ODI = Owestry Disability Index
OLIF = Oblique Lumbar Interbody Fusion
OPLL = Ossification of the Posterior Longitudinal Ligament
PC = Perineural Cysts
PCA = Patient Controlled Analgesia
PECD = Percutaneous Endoscopic Cervical Discectomy
PEEK = Polyether Ether Ketone
PICA = Posterior Inferior Cerebellar Artery
PLIF = Posterior Lumbar Interbody Fusion
PLL = Posterior Longitudinal Ligament
PSO = Pedicle Subtraction Osteotomies
RF = Radiofrequency
RFD = Radiofrequency Facet Denervation
ROM = Range of Motion
SAP = Superior Articular Process

SCD = Spinal Cord Decompression
SCM = Sternocleidomastoid Muscle
SDAVF = Spinal Dural Arteriovenous Fistulas
SEAC = Spinal Extradural Arachnoid Cyst
SPO = Smith-Petersen Osteotomies
SSEP = Somatosensory-Evoked Potential
SSHQ = Self-Administered, Self-Reported History Questionnaire
TDH = Thoracic Disc Herniation
TES = Total *En Bloc* Spondylectomy
TIS = Thoracic Insufficiency Syndrome
TLIF = Transforaminal Lumbar Interbody Fusion
TS = Thecal Sac
TTA = Transthoracic Approach
VANRC = Vertebral Artery - Nerve Root Complex
VAS = Visual Analogue Scale
VATS = Video-Assisted Thoracoscopic Surgery
VEPTR = Vertical Expandable Prosthetic Titanium Rib
VHL = Von Hippel-Lindau
XLIF = Extreme Lateral Interbody Fusion

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