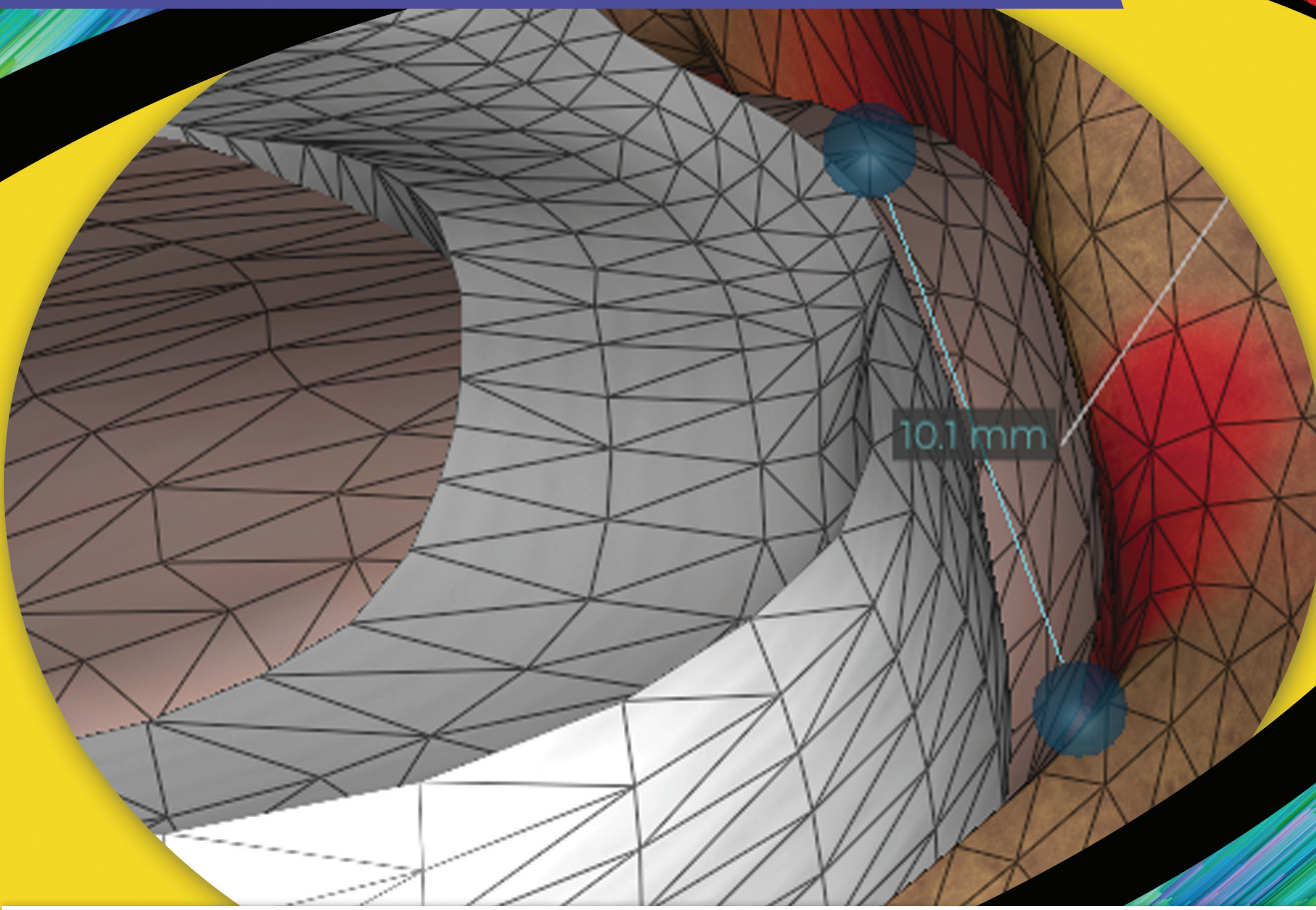
CONTEMPORARY ENDOSCOPIC SPINE SURGERY

VOLUME 3

ADVANCED TECHNOLOGIES



Editors:

Kai-Uwe Lewandrowski

Jorge Felipe Ramírez León

Anthony Yeung

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Contemporary Endoscopic Spine Surgery

(Volume 3)

Advanced Technologies

Edited by

Kai-Uwe Lewandrowski
Center For Advanced Spine Care
Tucson
Arizona
USA

Jorge Felipe Ramírez León
Fundación Universitaria Sanitas
Clínica Reina Sofía – Clínica Colsanitas
Centro de Columna – Cirugía Mínima Invasiva
Bogotá, D.C.
Colombia

Anthony Yeung
University of New Mexico
School of Medicine
Albuquerque
New Mexico, USA

Assistant Editors

Hyeun-Sung Kim

Department of Neurosurgery
Nanoori Gangnam Hospital
Seoul
Republic of Korea

Xifeng Zhang

Department of Orthopedics
First Medical Center
PLA General Hospital
Beijing 100853
China

Gun Choi

Neurosurgeon and Minimally Invasive Spine Surgeon
President Pohang Wooridul Hospital
South Korea

Stefan Hellinger

Department of Orthopedic Surgery
Arabellaklinik
Munich
Germany

Álvaro Dowling

Endoscopic Spine Clinic
Santiago
Chile

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Editors: Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León and Anthony Yeung

Assistant Editors: Hyeun-Sung Kim, Xifeng Zhang, Gun Choi, Stefan Hellinger and Álvaro Dowling

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ENDORSEMENTS

ISASS

The International Society for the Advancement of Spine Surgery (ISASS; formerly The Spine Arthroplasty Society) has its roots in motion preservation as an alternative to fusion. Since then, it has worked to achieve its mission of acting as a global, scientific and educational society with a surgeon-centered focus. ISASS was organized to provide an independent venue to discuss and address the issues involved with all aspects of basic and clinical science of motion preservation, stabilization, innovative technologies, MIS procedures, biologics, and other fundamental topics to restore and improve motion and function of the spine. ISASS has a robust international membership of orthopedic and neurosurgery spine surgeons and scientists. ISASS is dedicated to advancing evolutionary and innovative spinal techniques and procedures such as endoscopic spine surgery. Every editor of Contemporary Endoscopic Spine Surgery represents ISASS as a member, author, reviewer, or editor of its quarterly circulation – The International Journal of Spine Surgery (IJSS). The contributors of *Contemporary Endoscopic Spinal Surgery* have succeeded in compiling an exhaustive and up-to-date reference text. It is an example of our society's mission pursuit of surgeon education and scientific study. It is my pleasure to endorse this comprehensive text on behalf of ISASS.

Domagoj Coric
President
International Society for the Advancement of Spine Surgery (ISASS)
Illinois
USA

SBC

Founded on October 12, 1994, the Brazilian Spine Society (Sociedade Brasileira de Coluna - SBC) is a scientific, non-profit organization whose primary objective is the advancement of spine surgery through basic research and clinical study in orthopedics and neurosurgery. SBC is actively engaged in the accreditation and continued education of spine surgeons in Brazil. It prides itself on bringing the latest high-grade scientific evidence on novel technological advances and therapies to its professional members. SBC pursues this mission with its quarterly circulation Coluna/ Columna and its online courses, including Introduction to Endoscopy. The authors and editors of Contemporary Endoscopic Spine Surgery have put forward a comprehensive reference text essential to SBC's core curriculum of teaching spinal endoscopy to the next generation of surgeons. The presented clinical protocols for the endoscopic treatment of cervical and lumbar spine conditions are vetted and validated by peer-reviewed articles published by its contributors. It is my pleasure to endorse Contemporary Endoscopic Spine Surgery on behalf of the Brazilian Spine Society.

Cristiano Magalhães Menezes
President of the Brazilian Spine Society (Sociedade Brasileira de Coluna - SBC)
São Paulo
Brazil

MISS OF COA

The Minimally Invasive Spine Surgery (MISS) of Chinese Orthopaedic Association (COA) was founded in 2003, which is one of the most special subsidiary societies of Chinese Medical Association, aiming to promote and develop minimally invasive orthopedics especially spine surgeries in China.

The MISS society organizes global discussions and encourages our members to participate international efforts and cooperation to improve surgeon education. With this mission in mind, it is my pleasure to endorse Contemporary Endoscopic Spine Surgery on behalf of the MISS of COA. Many international editors and contributors are from China, who have made great efforts, contributions and dedications to this book. They share with and update readers all over the world about the latest endoscopic spinal surgery techniques. I am confident that *Contemporary Endoscopic Spinal Surgery* can be a textbook for spine surgeons. It should be used as medical school advanced lessons materials for continuing education courses. In sum, it is my pleasure and honor to support it on behalf of the MISS of COA.

Huilin Yang
Chairman of MISS of COA
Professor & Chairman of Orthopedic Department
The First Affiliated Hospital of Soochow University
Suzhou
China

SICCMI

SICCMI (Sociedad Interamericana De Cirugia De Columna Minimamente Invasive) was founded in 2006 with similar objectives pursued by the editors of Contemporary Endoscopic Spine Surgery: the advancement and mainstreaming of minimally invasive spine surgery (MIS). SICMII members joined to implement MIS in all countries of South America, the Caribbean, Central America, and North America. Endoscopic surgery is performed by many of its key opinion leaders at the highest level, some of which have contributed to this multi-volume text. Four of the editors are active SICCMI members in leadership positions. The book contents are exhaustive and comprehensive, encompassing topics of the cervical and lumbar spine and advanced technology applications. Contemporary Endoscopic Spine Surgery will serve as SICCMI's core curriculum and course material for endoscopic surgery of the spine. It is my pleasure to endorse it on behalf of SICCMI.

President of SICCMI
Manuel Rodriguez
President-Elect of SICCMI, Department of Neurosurgery
ABC Medical Center
Ciudad de México, Mexico

SBMT

As a nonprofit organization, the Society for Brain Mapping and Therapeutics (SBMT) focuses on improving patient care by translating new technologies into life-saving diagnostic and therapeutic procedures. Contemporary Endoscopic Spine Surgery is a prime example of achieving excellence in education and scientific discovery. Authors and editors from around the globe came together to present the reader with the most up-to-date endoscopic spine surgery protocols and their supporting clinical evidence. SBMT has an active spine section led by productive innovator surgeons – some of which have demonstrated their leadership with their editorial contributions to *Contemporary Endoscopic Spinal Surgery*. The editors have embraced multidisciplinary collaborations across many cultural and geographic barriers. Their effort represents one of the core principles of SBMT's mission: to identify and bridge gaps in modern patient care with technological advances. It is my pleasure to endorse *Contemporary Endoscopic Spinal Surgery* on behalf of SBMT.

Babak Kateb
Founding Chairman of the Board of Directors
CEO and Scientific Director of SBMT
Californias
USA

SILACO

SILICO (Sociedad Ibero Latinoamericana de Columna) had its beginnings in the meetings of the Scoliosis Research Society with the first Hispano-American Congress held in 1991 in Buenos Aires Argentina. Since then, it has morphed into an organization that promotes the study of treatments and prevention of spinal conditions by bringing together spine care professionals from all subspecialties. The scientific activities of our biannual Ibero-Latin American Congress are focused on the promotion of surgeon education to the highest academic standards via international relationships between members from the Americas, Spain and Portugal.

Contemporary Endoscopic Spine Surgery resembles such a collaborative effort where authors worldwide have come together to update the reader on the latest endoscopic spinal surgery techniques.

SILACO has incorporated Contemporary Endoscopic Spine Surgery into its core curriculum and plans on using it as course material for its continuing education courses. It is my pleasure to endorse it on behalf of SILACO.

Jaime Moyano
President of SILACO
Editor Revista De Sociedad Ecuatoriana De Ortopedia y Traumatología
de la Sociedad Ecuatoriana De Ortopedia Y Traumatología
Quito, Ecuador

SOMEEC

SOMEEC- Sociedad Mexicana de Endoscopia de Columna- is Mexico's prime organization uniting spine surgeons with a diverse training background having a fundamental interest in endoscopic surgery. SOMEEC organizes annual meetings where member surgeons and international faculty update each other on their latest clinical research to promote spine care *via* endoscopic spinal surgery technique. Two of the senior lead editors of *Contemporary Endoscopic Spinal Surgery* have been active international supporters of SOMEEC. I am pleased to endorse their latest three-volume reference text, which will become an integral centerpiece of SOMEEC's continuing medical educational programs.

Cecilio Quinones
Past President of the Sociedad Mexicana de Endoscopia de Columnas

KOSESS

The Korean Research Society of Endoscopic Spine Surgery (KOSESS) was established in 2017. KOSESS was founded to bring endoscopic spine surgeons in the Republic of Korea together to advance the subspecialty of endoscopic spine surgery with high-quality clinical research. It is reflected in *Contemporary Endoscopic Spine Surgery* by the numerous contributions of Korean authors. It is *Contemporary Endoscopic Spine Surgery*. It is my pleasure to endorse it on behalf of KOSESS.

Hyeun-Sung Kim (Harrison Kim)
President of the Korean Research Society of the Endoscopic Spine Society (KOSESS)
Seoul
Republic of Korea

KOMISS

Since its establishment in 2002, the *Korean Minimally Invasive Spinal Surgery Society* (KOMISS) has had a leading role in developing new clinically applicable technologies to advance patient care with less invasive yet more effective therapies. The superiority of minimally invasive spine surgery in Korea is demonstrated by its competitiveness on the world stage at the highest academic level. It is reflected in *Contemporary Endoscopic Spine Surgery* by the numerous Korean authors who have contributed to this timely reference text with their groundbreaking clinical research on endoscopic spine surgery. I am proud of their accomplishments and want to congratulate them on acting as KOMISS ambassadors by carrying the message of Korean excellence in minimally invasive spinal surgery the world over within *Contemporary Endoscopic Spine Surgery*. It is my pleasure to endorse it on behalf of KOMISS.

Dae Hyun Kim
President of KOMISS
Seoul
Republic of Korea

NATIONAL ACADEMY OF MEDICINE OF COLOMBIA

After reviewing the table of content and some representative chapters, I am happy to inform you that the Board of Directors of the National Academy of Medicine of Colombia grants academic endorsement of your book series entitled Contemporary Endoscopy Spine Surgery. Kai-Uwe Lewandrowski, Jorge Felipe Ramírez, and Anthony Yeung produced a text of great interest and scientific impact.

On behalf of the National Academy of Medicine, I would like to express my admiration and respect for your dedication to scientific research that led to this great work's culmination. It meets the high standards required by our National Academy to support such a production spearheaded by one of our most esteemed members - Dr. Jorge Felipe Ramírez.

Gustavo Landazabal Bernal
General Secretary
National Academy of Medicine of Colombia
Bogota, Colombia

IITS

International Intradiscal Therapy Society

The International Intradiscal Therapy Society (IITS) was founded in 1987, initially headquartered in Belgium, Wisconsin, and led by Dr. Eugene Nordby, the first Executive Director of IITS. Members were primarily orthopaedic surgeons, anesthesiologists, radiologists, and rheumatologists dedicated to the treatment, research, and education involving The FDA-approved and validated level I studies that supported intradiscal spinal therapies.

From 2013-2017, the society began operating under International Intradiscal and Transforaminal Therapy Society (IITTSS) to reflect the advancements in endoscopic spine surgery augmenting Intradiscal therapy. The organization wanted to include and reflect the state-of-the-art evolution in intradiscal therapy with advances by intradiscal visualization of pain generators through the endoscope. However, the society reverted to IITS.

IITS now sponsors workshops on intradiscal therapy in conjunction with other International societies when it lost its original pharma support. IITS disseminates a newsletter to provide its membership, other healthcare professionals, and the general public information on the safest and cost-effective techniques to treat conditions such as herniated nucleus pulposus and other intradiscal spinal disorders.

IITS is a 501C3 non-profit organization whose focus is on intradiscal therapy aided by the endoscope as the least invasive, visually-guided treatment for discogenic pain, including extra-discal and complex foraminal decompression and stabilization procedures. The disc has been validated as the primary initial source of common back pain.

Two of the senior lead editors of Contemporary Endoscopic Spinal Surgery have been in active leadership roles in International Spine Organizations as consultants, full and associate professors, and directors. I am pleased to endorse their latest three-volume reference text, which will become integral to IITS' ongoing course programs.

Anthony Yeung
Executive Director of IITS
Desert Institute for Spine Care
Phoenix, Arizona
USA

SLAOT

The Sociedad Latinoamericana de Ortopedia y Traumatologia (SLAOT)/ Latin American Society of Orthopaedics and Traumatology is a non-profit, autonomous, scientific organization of orthopaedic surgeons and orthopaedic care professionals. SLAOT has an organization structure that brings together professionals with a diverse scientific interest. It promotes continuous professional development and education at the highest level. *Contemporary Endoscopic Spine Surgery* is of interest to SLAOT because of its illustrative use of cutting-edge technology and discussion of validated clinical endoscopic spinal surgery protocols. It is my pleasure to endorse *Contemporary Endoscopic Spine Surgery* on behalf of SLAOT.

Horacio Caviglia
President of SLAOT FEDERACION
USA

CONTENTS

PREFACE

Spinal endoscopy is a technology-driven subspecialty of spinal surgery. The increased clinical traction and acceptance of minimally invasive endoscopic spinal surgery techniques result in successful technology transfers from other industries. Image quality in endoscopy is perceived by magnification, depth of field, resolution, color truth, and high image contrast, as well as low distortion and homogeneous illumination up to the edge of the image. The introduction of HD technology in 2005 to the general consumer market forced endoscope manufacturers to develop endoscopes that provided optimized image quality for the HD Video chain. Some of these technological advancements in 2000 coincided with the introduction of the endoscope into transforaminal spinal surgery. Newer clinical indications for endoscopic spine surgery are aimed to replace traditional translaminar surgeries. This expansion of the endoscopic spinal surgery platform is fueled by technology transfers from the space-, military- or consumer sector developments in the area of illumination, image quality, and high-definition video quality. It also hinges on the development of more durable and stress-resistant spinal endoscopes requiring continued expert surgeon input. Illustrating the application of these technological advancements in endoscopic spine surgery is at the heart of the third volume of the Bentham Series entitled "*Contemporary Endoscopic Spine Surgery*."

The editors have come together to develop a multi-authored and clinically focused medical monograph entitled *Contemporary Endoscopic Spine Surgery: Advanced Technologies* to give the reader a most up-to-date snapshot of the current and future technology advances in spinal endoscopy. The publication is intended for Orthopedic Spine & Neurosurgeons interested in treating common painful conditions of the spine with minimally invasive endoscopic techniques. A wide array of highly timely and clinically relevant topics have been assembled for this purpose. They range from the historical review of intradiscal therapies and foraminoplasty techniques, the discussion of the disruptive approach to personalized pain generator-oriented spine care *versus* population-based evidenced-based treatment strategies in context with modern clinical classification systems, the application of lasers, radiofrequency, and regenerative medicine strategies, the use of artificial intelligence and decision algorithms employed in the interpretation of advanced imaging studies to more accurately identify pain generators and their management with denervation and surgical strategies, the management of postoperative sequelae and complications, the indications for efficacious use of interspinous implants and fusion techniques, to the cost of implementing and maintaining a clinical endoscopic spine care program and advanced endoscopic technique for the most challenging clinical problems.

Future advances in clinical protocols will likely be driven by higher image quality standards that may provide the basis for artificial intelligence applications in image recognition, robotics, integration and automatization of surgical processes. *Contemporary Endoscopic Spine Surgery: Adavanced Technologies* was written with these trends in mind. The editors hope that the readers will find it an informative knowledge resource they will continue to revert to when implementing a lumbar endoscopic spinal surgery program in their practice setting.

Kai-Uwe Lewandrowski
Center for Advanced Spine Care of Southern Arizona
and
Surgical Institute of Tucson
Tucson, AZ
USA

Departmemt of Orthopaedics
Fundación Universitaria Sanitas
Bogotá, D.C.
Colombia

Department of Orthopedics at Hospital Universitário Gaffree
Guinle Universidade Federal do Estado do Rio de Janeiro
Rio de Janeiro
Brazil

Jorge Felipe Ramírez León
Fundación Universitaria Sanitas
Clínica Reina Sofía – Clínica Colsanitas
Centro de Columna – Cirugía Mínima Invasiva
Bogotá, D.C.
Colombia

Anthony Yeung
University of New Mexico
School of Medicine
Albuquerque
New Mexico
USA

List of Contributors

Álvaro Dowling	Department of Orthopaedic Surgery, USP, Ribeirão Preto, Brazil
André Luiz Calderaro	Centro Ortopedico Valqueire, Departamento de Full Endoscopia da Coluna Vertebral, Rio de Janeiro, Brazil
Anthony Yeung	University of New Mexico School of Medicine, Albuquerque, New Mexico Desert Institute for Spine Care, Phoenix, AZ, USA
Bu Rongqiang	Department of Orthopedics, Beijing Yuho Rehabilitation Hospital, Beijing, 100853, China
Byapak Paudel	Department of Neurosurgery, Nanoori Gangnam Hospital, Seoul, Republic of Korea Department of Orthopaedics & Traumatology, Grande International Hospital, Kathmandu, Nepal
Du Jianwei	Department of Orthopedics, Affiliated Hospital of Yangzhou University, Yangzhou, 225001, China
Friedrich Tieber	Medical Technologies Consulting, Augsburg, Germany
Hyeun-Sung Kim	Nonhyeon-dong, Gangnam-gu, Nanoori Hospital, Seoul, South Korea
Ibrahim Hussain	Department of Neurological Surgery, University of Miami, Miami, FL 33136, USA
Il-Tae Jang	Department of Neurosurgery, Nanoori Gangnam Hospital, Seoul, Republic of Korea
Jiang Letao	Department of Orthopedics, Affiliated Hospital of Yangzhou University, Yangzhou, 225001, China
Jorge Felipe Ramírez León	Orthopedic and Minimally Invasive Spine Surgeon; Reina Sofía Clinic and Center of Minimally Invasive Spine Surgery, Bogotá Colombia. Chairman, Spine Surgery Program, Universidad Sanitas, Bogotá, D.C., Colombia, USA
Juan Carlos Vera	Molecular Biotechnology Engineer-Universidad de Chile Business Development Manager-VidaCel, Chile
Kai-Uwe Lewandrowski	Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson, AZ, USA Departmemt of Orthopaedics, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA Department of Neurosurgery in the Video-Endoscopic Postgraduate Program at the Universidade Federal do Estado do Rio de Janeiro, UNIRIO, Rio de Janeiro, Brazil
Lei-Ming Zhang	Department of Orthopedics, Beijing Yuho Rehabilitation Hospital, Beijing, 100853, China
Max Rogério Freitas Ramos	Federal University of the Rio de Janeiro State UNIRIO, Associate Professor of Orthopedics and Traumatology, Rio de Janeiro - RJ, Brazil Head of Orthopedic Clinics at Gaffrée Guinle University Hospital HUGG, Rio de Janeiro - RJ, Brazil

Michael Y. Wang	Professor of Neuosurgery Department of Neurological Surgery, University of Miami, Miami, FL 33136, USA
Narendran Muraleedharan Basme	Aptus Engineering, Inc, Scottsdale, Arizona, and Multus Medical, LLC, Phoenix, Arizona, USA
Nicholas A Ransom	Director of Endoscopic Spine Clinic, Orthopaedic Spine Surgeon, Santiago, Chile
Nitin Maruti Adsul	Department of Neurosurgery, Nanoori Gangnam Hospital, Seoul, Republic of Korea Sir Ganga Ram Hospital, Ortho-Spine Surgery, New Delhi, India
Paulo Sérgio Teixeira de Carvalho	Department of Neurosurgery, Universidade Federal do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
R. Cantú-Leal	Department of Spine Surgery, Hospital Christus Muguerza Alta Especialidad in Monterrey, Mexico
R. Cantu-Longoria	Orthopaedic Spine Surgeon, Hospital Christus Muguerza Alta Especialidad, Villa Alegre C.P. 64130 Monterrey. N.L, Mexico
Sandeep Shah	Multus Medical, LLC, Phoenix, Arizona, USA
Stefan Hellinger	Department of Orthopedic Surgery, Arabellaklinik, Munich, Germany
Vikram Sobti	Innovative Radiology, PC, River Forest, Illinois, USA
Vincent Hagel	Asklepios Hospital Lindau, Spine Center, Lindau, Germany
Xifeng Zhang	Department of Orthopedics, First Medical Center, PLA General Hospital, Beijing 100853, China Department of Orthopedics, Beijing Yuho Rehabilitation Hospital, Beijing, 100853, China

CHAPTER 1

The History and Future Value of Endoscopic Intradiscal Therapy and Foraminoplasty

Anthony Yeung[1,*] and **Kai-Uwe Lewandrowski**[2,3,4]

[1] *Clinical Professor, University of New Mexico School of Medicine, Albuquerque, New Mexico, Desert Institute for Spine Care, Phoenix, AZ, USA*

[2] *Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson AZ, USA*

[3] *Departmemt of Orthopaedics, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA*

[4] *Department of Neurosurgery in the Video-Endoscopic Postgraduate Program at the Universidade Federal do Estado do Rio de Janeiro — UNIRIO, Rio de Janeiro, Brazil*

Abstract: The utilization of spinal endoscopic surgery techniques is on the rise in routine clinical practice and treating painful annular tears, herniated disc, and spinal stenosis. Over the past ten years, we have witnessed an increasing number of surgeons recognizing spinal endoscopy's value. Many of them had difficulty finding access to adequate training while facing reimbursement and acceptance problems. In this chapter, the authors describe the implementation issues at play that they perceive as relevant in the discussion between the healthcare equation's stakeholders. Included in this chapter on the forward-looking perspective of spinal endoscopy is the first author's involvement in the role and value of laser and electrothermal therapy, which is still pertinent but has evolved with advancements in technology and endoscopes and instrumentation.

Keywords: Endoscopic surgery, Foraminoplasty, History & Future, Intradiscal therapy.

INTRODUCTION

Surgeons and surgically trained non-surgeons will advance the future success of endoscopic spinal surgery. The number of endoscopic and minimally invasive spinal surgeries has been predicted to increase the spine surgery market at a compound annual growth rate of 7.57 percent between 2016 and 2020 in North America and Europe alone [1]. The explosion of endoscopic spine surgeries in

* **Corresponding author Anthony Yeung**: Clinical Professor, University of New Mexico School of Medicine, Albuquerque, New Mexico, Desert Institute for Spine Care, Phoenix, AZ, USA and ; E-mail: ayeung@sciatica.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

Asia has been recently illustrated by analyzing the country of residence of the authors of scholarly articles published in peer-reviewed SCI(E) journals within the last five years [2]. Authors from China, South Korea, the USA, Germany, and Japan have published the vast majority of papers. The most prolific authors came from a few number of well-recognized institutions, including the Wooridul Spine Hospital in Seoul, South Korea, The Tongji University and the Third Military Medical University in China, the University of Witten/Herdecke in Germany, Brown University, The Center For Advanced Spine Care of Southern Arizona, and from the Desert Institute of Spine Care, Phoenix, in the USA. Endoscopic spinal surgery is expected to become more mainstream globally by increasingly augmenting or replacing traditional open spinal surgeries with less aggressive procedures that are less invasive but equally, if not more beneficial to the patient.

The expanding number of indications that surgeons now identify as appropriate for endoscopic treatment of the spine's common degenerative conditions suggest that there is more to it than merely miniaturizing incisions and performing surgery under local anesthesia sedation. The direct visualization of the intradiscal pathology, pathology in the epidural space, and neural elements in the axilla allow for the diagnosis of pain generators that previously have not been visualized and recognized as treatable conditions. Even more relevant is the ability to correlate the pathophysiology of pain with visualized pathoanatomy with the endoscope. Examples include toxic and painful annular tears, epidural adhesions, scar tissue, and inflammatory granulomas. Other pain inducing patho-anatomy include superior foraminal ligament and facet impingement, facet joint cysts and impaction, tethering of the nerve roots to the pars interarticularis, the pedicles or the intertransverse membrane. Inflammatory irritation of the annulus, posterior longitudinal ligament, lateral and shoulder osteophytes (Tables **1** and **2**), and a myriad of endoscopically visualized intradiscal conditions ranging from fissuring, delamination of the endplates, to gaseous degeneration of the intervertebral disc leaving it hollow, and void of any functional tissues round out the myriad of patho-anatomy documented with the endoscope (Fig. **1**) [3].

With current diagnostic tools, including radiographs, computed tomography (CT), and magnetic resonance imaging (MRI), these conditions are difficult to establish before surgery. These pain generators may be insufficiently imaged with routine preoperative studies or just not included in imaging reporting by the radiologist, hence, leaving a large portion of patients that by new measures are considered either “too young,” or “too old” or having too much surgical morbidity without surgical treatment of their painful conditions. However, it will be in this grey area where highly qualified and experienced providers will use the endoscope to correlate the pathophysiology of the patients' symptoms with intraoperatively visualized pathoanatomy that can be decompressed, ablated, thermally modulated, and irrigated to provide pain relief from chemical as well as mechanical irritation and structural defects.

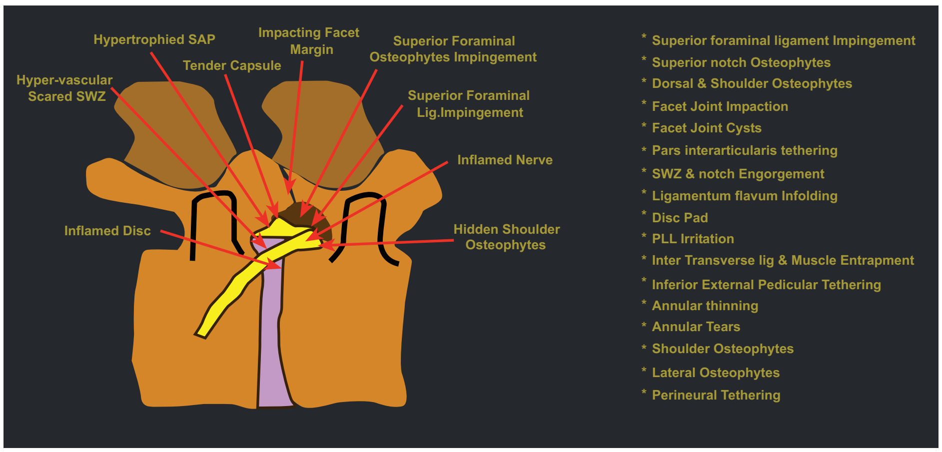

Fig. (1). Illustration of 9 common, and 19 endoscopically documented painful conditions and their anatomic locations in the foramen.

Table 1. Nine common endoscopically lumbar conditions visualized during foraminoplasty.

• Inflammed disc • Inflammed nerve • Hypervascular scar • Hypertrophies superior articular process (SAP), ligamentum flavum impingement • Tender capsule • Impacting facet margin • Superior foraminal facet osteophyte • Superior foraminal ligament impingement • Hidden shoulder osteophyte

Table 2. Additional conditions visualized during routine lumbar endoscopy.

• Symptomatic foraminal scar tissue • Facet joint impingement • Facet joint cysts • Parts defect tethering • PLL irritation • Annular thinning and tears • Perineural tethering by scar • Various foraminal osteophytosis locations • Endplate tethering and impingement

CHAPTER 2

Evidence Based Medicine *versus* Personalized Treatment of Symptomatic Conditions of the Spine Under Local Anesthesia: the Role of Endoscopic *versus* Spinal Fusion Surgery as a "Disruptive" Technique

Anthony Yeung[1] and **Kai-Uwe Lewandrowski**[2,3,4,*]

[1] *Clinical Professor, University of New Mexico School of Medicine, Albuquerque, New Mexico, Desert Institute for Spine Care, Phoenix, AZ, USA*

[2] *Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson AZ, USA*

[3] *Departmemt of Orthopaedics, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA*

[4] *Department of Neurosurgery in the Video-Endoscopic Postgraduate Program at the Universidade Federal do Estado do Rio de Janeiro — UNIRIO, Rio de Janeiro, Brazil*

Abstract: Runaway cost for surgical spine care has led to increased scrutiny on its medical necessity. Consequently, the beaurocracy involved in determining coverage for these services has grown. The call for high-grade clinical evidence dominates the debate on whether endoscopic surgery has a place in treating painful conditions of the aging spine. The cost-effectiveness and durability of the endoscopic treatment benefit are questioned every time technology advances prompt an expansion of its clinical indications. The authors of this chapter introduce the concept of early-staged management of spine pain and make the case for personalized spine care focused on predominant pain generators rather than image-based necessity criteria for surgery often applied in population-based management strategies. The authors stipulate that future endoscopic spine care will likely bridge the gap between interventional pain management and open spine surgery. This emerging field of interventional endoscopic pain surgery aims to meet the unanswered patient demand for less burdensome treatments under local anesthesia and sedation. The very young and old patients often are ignored because their conditions are either not bad enough or too advanced for a successful outcome with traditional spine care. In this watershed area of spine care, the authors predict endoscopic spine surgery will thrive and carve out accepted surgical

* **Corresponding author Kai-Uwe Lewandrowski:** Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson, AZ, USA, Department of Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil and Department of Orthoapedic Surgery, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA; Tel: +1 520 204-1495; Fax: +1 623 218-1215; E-mail: business@tucsonspine.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

indications in direct competition with pain management and traditional open spine fusion protocols.

Keywords: Endoscopy future, Pain generators, Personalized spine care, Staged endoscopic pain management.

INTRODUCTION

Clinical treatment guidelines are reflected in the health insurance industry's medical necessity and coverage rules. Many organizations and their "key opinion" leaders (KOLs) structure their medical and surgical treatments' narrative based on consensus finding and peer-reviewed articles. Health care, in general, is becoming more and more regulated and reliant on subsidies by the government or payers, making payments dependent on compliance with their treatments- and coverage guidelines and thereby increasing the bureaucracy in the delivery of healthcare on the backend to the individual patient. Bureaucratic hurdles have created more significant headwinds on the front end of the medical innovation cycle that effectively hamper the dissemination and publication of original and pioneering literature, which by definition starts with low-level V research and expert opinions. This low- level evidence is often unable to survive the rigorous review process of a medical publishing system geared towards publishing higher-level studies. Surgeon innovators often lack resources, institutional, and funding support to conduct prospective randomized single or multicenter trials. Even if able to orchestrate those trials, researchers in academic institutions are dependent on NIH or institutional support to get their clinical research published. Publication fees associated with many open-access Journals and the bureaucracy associated with traditional journals often requiring institutional review board (IRB) approval before submitting even low-level retrospective studies. This dynamic may pose additional unintended hurdles to disseminating novel and disruptive information, which is often created under the premise of reining in runaway healthcare cost.

In spine surgery, introducing new evidence in support of novel treatments can be particularly challenging since it is always compared to evidence relying on fusion as the ultimate solution. Combining these factors may hinder the entry of innovative clinical information into the mainstream peer-reviewed literature because spine surgeons, especially in a private practice setting, are too busy dealing with the increasing non-clinical and managerial workload while trying to pay clinical practice overhead. Academic surgeons may have institutional support, but the new challenges in endoscopic spine surgery can be daunting, whether in an academic or private setting. Endoscopic spine surgery is innovative but lacks traditional evidence-based criteria of conventional spine surgery for several reasons. First, the number of surgeons performing endoscopic spine surgery is still significantly less than surgeons performing traditional and other forms of translaminar minimally invasive spinal surgeries. The objectives of endoscopic spine surgery are different from other forms of spine surgery since it focuses on the patient's individual needs for their painful patho-anatomy of the spinal motion segment rather than treating pain syndromes from overt instability or severe spinal stenosis, which lends itself better for the study of outcomes and cost-effectiveness of lumbar spine surgery in a large population of patients. Third, by definition, endoscopic spine surgery is “disruptive” to the evidence-based medicine (EBM) study approach since there are many more study variables due to a large number of concurrent pain generators that are not considered for treatment with other forms of lumbar spine surgery. Taking all this into consideration, it comes as no surprise that true level I and II studies investigating the merits of endoscopic spine surgery are rare. In awake patients, randomization is not possible. Even level I and II studies are subject to different interpretations by academicians and payors. Most patients cannot receive meaningful treatment until their symptoms are out of control and all non-operative measures have failed. The many patients that cannot find help by institutionalized surgeons turn to alternative medicine and pain management to control their symptoms. Surgery is usually reserved for more severe conditions supported by traditionally accepted imaging studies.

TREATMENT NECESSITY RATIONALES

Radiologic imaging is alone often unable to explain the pain that does not meet medical necessity criteria for surgery. A lumbar MRI scan has been demonstrated not to correlate with the severity and low back pain duration [1]. In the treating physician’s and surgeon’s judgment, the disability may not be severe enough for consideration by traditional surgeons, especially when the risk and benefits of established spinal treatments and surgeries are factored in. Pain management treatments with narcotics, helpful or not, as well as a multitude of alternative medicine remedies, and durable medical equipment (DME) are often overutilized. For example, braces and home traction devices such as inversion tables are sold without prescription and are typically not covered by insurance. Some payors allow for chiropractic care. The concepts employed in endoscopy spine surgery are disruptive and will likely continue to be disruptive to our current established scientific validation system on large patient populations. If performed expertly and adequately, superior outcomes with endoscopic spine care can be provided in a more cost- effective and less burdensome manner both to the patient and the health care system as a whole.

CHAPTER 3

How to Generate the Superiority Evidence for Endoscopic Surgery for Common Lumbar Degenerative Conditions

Kai-Uwe Lewandrowski[1,2,3,*], **Jorge Felipe Ramírez León**[4] and **Anthony Yeung**[5]

[1] *Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson AZ, USA*

[2] *Associate Professor of Orthopaedic Surgery, Universidad Colsanitas, Bogota, Colombia, USA*

[3] *Visiting Professor, Department Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil*

[4] *Centro de Columna – Cirugía Mínima Invasiva. Bogotá, D.C., Colombia, Clínica Reina Sofía – Clínica Colsanitas. Bogotá, D.C., Colombia, Fundación Universitaria Sanitas , Bogotá, D.C., Colombia, USA*

[5] *Clinical Professor, University of New Mexico School of Medicine, Albuquerque, New Mexico Desert Institute for Spine Care, Phoenix, AZ, USA*

Abstract: Endoscopic spinal surgery affords the patient simplified and less burdensome spine care. Its superiority over open decompression surgeries has been long debated, and the current evidence is incomplete. The innovators and proponents of this procedure carry the burden of proof. The targeted endoscopic treatment of common spinal pain generators produces higher perioperative patient satisfaction than traditional spine surgery. This chapter discusses conventional spine surgery research's pros and cons of employing patient-reported outcome measures (PROM). They offer an alternative approach to establishing a better value proposition with the endoscopic *versus* open spinal surgery - the concept of durability analysis.

Keywords: Clinical evidence, Outcome analysis, Spinal endoscopy, Statistics.

THE BURDEN OF PROOF

Endoscopic spine surgery is undoubtedly on the rise in many developed countries [1 - 3]. This trend is fueled by technological advances and favorable clinical

* **Corresponding author Kai-Uwe Lewandrowski:** Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson, AZ, USA, Department of Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil and Department of Orthoapedic Surgery, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA; Tel: +1 520 204-1495; Fax: +1 623 218-1215; E-mail: business@tucsonspine.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

studies supporting its routine clinical use [4]. However, its critics still torment the lack of sufficient high-grade evidence to acknowledge its role in a modern degenerative spine practice, and some of them may never embrace it regardless [5, 6]. Since the burden of proof is on the proponents of endoscopic spinal surgery, the question raises how to demonstrate its efficacy and perhaps even areas of superiority over traditional open and other forms of minimally invasive spinal surgery techniques. Typically, there is a call for prospective randomized trials to deliver on the request for high-grade clinical evidence [5]. However, as we will outline below, this is not all that practical at times, and even the well-funded multicenter studies around the Spine Outcome Research Trial (SPORT) [7 - 10] or the Surgical Timing In Acute Spinal Cord Injury Study (STASCIS) [11] failed to provide the high-grade evidence they were designed to provide. Nevertheless, this type of evidence is frequently requested by payors and review boards to establish the medical necessity for endoscopic surgery. Repeated calls for this high-grade clinical evidence reappear when the cost of capital equipment purchases, disposables, and additional training is considered, which seemingly contributes to the escalating cost of spine care. This gap between the available clinical evidence - most of which is level III evidence comprised of retrospective endoscopic case series and a few Level I and II prospective randomized trials published comparing endoscopic- *versus* microsurgical decompression - and the need to demonstrate the clinical value preposition in endoscopic surgery poses the question how to accomplish that best.

Several authors have attempted to bridge this evidence gap by orchestrating high-grade evidence studies. For example, Ruetten [12 - 14], Komp [15, 16], and their respective team have published their results with the full endoscopic lumbar decompression for lateral recess stenosis *versus* conventional microsurgical technique 2009 [12]. In their randomized prospective controlled trial, which included some 161 patients, they were able to show similar clinical outcomes employing the German version of the North American Spine Society instrument and the Oswestry low back pain disability questionnaire. In different studies on 178 patients, the same authors reported complete leg pain relief in 82% of the patients' two-year follow-up. Only 14% of their patients complained of some occasional pain, with the overall clinical outcomes being similar between traditional microdiscectomy and full endoscopic discectomy, including recurrence rates of 6.2%. Hence, they believed that full-endoscopic techniques are of higher value than conventional decompression techniques since it provides significant advantages, including less back pain, improved rehabilitation, fewer complications, and less traumatization. However, they also recognized the need for objective data to support this notion. In 2011, Ruetten and his team attempted to close that gap by reporting on 87 patients with recurrent herniation after conventional discectomy. These patients underwent full-endoscopic or microsurgical intervention, and again similar clinical outcomes with a 79% success rate and re-recurrence rate of 5.7% were reported [16].

Several authors employed the meta-analysis tool in an attempt to provide high-grade evidence on spinal endoscopy. For example, Birkenmeier et al. compared controlled clinical trials on endoscopic and microsurgical standard procedures [17]. In 2013, his review of full-endoscopic interlaminar and transforaminal approaches for all spinal regions initially included 504 PubMed and Embase listed articles. Ultimately, four randomized controlled trials (RCTs) and one controlled study (CS) were identified that met the inclusion eligibility criteria. Stratifying these studies for randomization, inclusion and exclusion criteria, clinical outcomes, and complications, Birkenmeier was able to show that shorter surgeries, decreased blood loss, less surgical wound pain, and faster postoperative rehabilitation, shorter hospital stay, earlier return to work when patients had surgery with the endoscopic techniques *versus* the microsurgical techniques were reported [17]. Clinical outcomes were similar between the endoscopic and the microsurgical methods in any of the trials. The complication rate was lower in all five studies when patients underwent endoscopic *versus* microsurgical discectomy. Revision conversion to fusion was reported by one study to be lower with the endoscopic procedure.

Another comparative study on endoscopic lumbar discectomy *versus* microsurgical laminotomy was published by Kong et al. in 2018 [18]. Although this study included only 40 patients with available two-year follow-up data, it was able to show equivalent numbers for ODI and VAS for back pain and leg reductions with either. This finding was corroborated by a treatment open-label randomized single-center trial conducted by Limin Rong et al. These authors compared the transforaminal endoscopic discectomy to translaminar microdiscectomy [19]. This study included 153 patients who were randomized to either of these two treatments. Clinical outcomes were analyzed to reduce the ODI, VAS back and VAS leg, SF-36, and the EuroQol Group's EQ-5D. Besides the length of surgery, hospital stay, mobilization time, surgery- and total hospital cost, the authors evaluated complications-, and reoperations rates. The clinical result differences between the two treatments showed equal ODI outcomes, but in medial disc herniations, endoscopy rendered less favorable results ($p = 0.027$). On the contrary, far lateral disc herniation treated with translaminar microsurgical decompression was associated with less favorable ODI outcomes at three months ($p = 0.008$), six months ($p = 0.028$), and one year ($p = 0.028$). An increasing distance of the pathology from the surgical access point was a predictor of deteriorating outcomes. There was no difference in the complication rates - 13.75% in the endoscopic surgery group and 16.44% in the microsurgical tubular retractor group ($p = 0.642$). At 1-year follow-up, the endoscopic surgery

CHAPTER 4

Artificial Intelligence Algorithms in the Identification and Demonstrating of Pain Generators Treated with Endoscopic Spine Surgery

Sandeep Shah[1], **Narendran Muraleedharan Basme**[2], **Vikram Sobti**[3], **Jorge Felipe Ramírez León**[4] and **Kai-Uwe Lewandrowski**[5,6,7,*]

[1] *Multus Medical, LLC, Phoenix, Arizona, USA*

[2] *Aptus Engineering, Inc, Scottsdale, Arizona, and Multus Medical, LLC, Phoenix, Arizona, USA*

[3] *Innovative Radiology, PC, River Forest, Illinois, USA*

[4] *Centro de Columna – Cirugía Mínima Invasiva. Bogotá, D.C., Colombia, Clínica Reina Sofía – Clínica Colsanitas. Bogotá, D.C., Colombia, Fundación Universitaria Sanitas , Bogotá, D.C., Colombia, USA*

[5] *Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson AZ, USA*

[6] *Departmemt of Orthopaedics, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA*

[7] *Visiting Professor, Department of Orthopaedics, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA*

Abstract: Identifying pain generators in multilevel lumbar degenerative disc disease focuses on artificial intelligence (AI) applications in endoscopic spine care to assure adequate symptom relief with the targeted endoscopic spinal decompression surgery. Artificial intelligence (AI) applications of deep learning neural networks to analyze routine lumbar MRI scans could improve clinical outcomes. One way to accomplish this is to apply AI management of patient records using a highly automated workflow, highlighting degenerative and acute abnormalities using unique three-dimensional patient anatomy models. These models help with the identification of the most suitable endoscopic treatment protocol. Radiology AI bots could help primary care doctors, specialists including surgeons and radiologists to read the patient's MRI scans and more accurately and transcribe radiology reports.

[*] **Corresponding author Kai-Uwe Lewandrowski:** Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson, AZ, USA, Department of Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil and Department of Orthoapedic Surgery, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA; Tel: +1 520 204-1495; Fax: +1 623 218-1215;
E-mail: business@tucsonspine.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

In this chapter, the authors introduce the concept of AI applications in endoscopic spine care and present some initial feasibility data validating its use based on intraoperatively visualized pathology. This research's ultimate objective is to assist in the development of AI algorithms predictive of the most successful and cost-effective outcomes with lumbar spinal endoscopy by using the radiologist's MRI grading and the grading of an AI deep learning neural network (Multus Radbot™) as independent prognosticators.

Keywords: Artificial intelligence, Endoscopic spinal surgery, Magnetic resonance imaging, Pain generator prognostication.

INTRODUCTION

The role of digital health applications is improving health and patient care. In endoscopic spine care, this translates into a better understanding of the relevant pain generator. The typical multilevel degenerative spine disease with nerve root entrapment due to spinal stenosis is of particular relevance. Deep learning neural networks – artificial intelligence (AI) – have been applied in routine lumbar MRI scan assessment to improve diagnostic accuracy and reliability [1 - 3]. Additional benefit may be in improving information- and workflow in managing symptomatic patients suffering from sciatica-type low back and leg pain [4 - 6]. The diagnostic gap in routine lumbar MRI reporting has been estimated to be as high as 35% when basing clinical decision making in lumbar spine care solely on images [7]. While one approach is to take additional diagnostic tests and protocols into account [8], another one is to think of ways to improve the prognostic value of the information extracted from the MRI scan. This involves extending the routine lumbar MRI scan beyond merely assessing mechanical compression and correlating directly visualized pathology with information buried within the DICOM data set of the MRI scan [9].

Traditionally, the radiologist provides a severity grading by subjective visual analysis of advanced cross-sectional MRI imaging of the spine [10 - 12]. Rarely, actual objective measurements of the diseased spinal motion segments' dimensions are provided in routine reporting. These omissions leave room for errors, which may stall the referral to specialists for appropriate care and overutilization in other areas [13], rarely addressing the patients' disability definitively stemming from the underlying structural abnormality [14 - 19]. The personal [14, 16 - 21] and professional burden of poorly controlled pain, lack of strength, coordination, or insufficient endurance is immense [20, 22]. Rather than continuing on the path of escalating costs, which will likely prompt rationing of medical services [23 - 26], AI aims to [27 - 34] provide targeted care to those patients who will likely benefit from it. To provide such targeted care more consistently, a higher-level of accuracy is required in the utilization of the routine MRI scan.

The endoscopic spine surgeon authors of this chapter became interested in collaborating with the other authors on AI applications for several reasons. There is a need for better prognosticators in the preoperative diagnostic process to steer this minimally invasive targeted decompression procedure at the pain generators causing the patient's symptoms [1]. Since this involves ignoring other potential abnormal findings on preoperative imaging studies, the diagnostic value of the AI prognosticators used needs to be higher than routine reporting, which often may underrepresent clinical pathology and therefore not trigger appropriate referrals to specialists and, thus, delay initiation of definitive spine care beyond the scope of generic referrals to physical therapy, and pain management regardless of whether or not successful or even needed. Frustrated with the frequent delay in appropriate spine care delivery, the authors of this chapter also aimed to investigate the merits of AI applications in endoscopic spine care based on workflow improvements. Automatically generated MRI reports could initiate the most appropriate referral to non-surgical and surgical specialists.

This chapter presents some initial feasibility and reliability data of clinical application of these AI concepts in endoscopic spine care of patients suffering from sciatica due to herniated disc. Ultimately, the author's goal was to develop more useful diagnostic tools to isolate pain generators in the lumbar spine and illustrate them to patients with 3D illustrations and animations to solidify the rationale for simplified yet effective targeted endoscopic treatments - a stark contrast to image-based medical necessity criteria which often lead to extensive open surgeries in the thoracolumbar spine.

WORKFLOW AUTOMATION

The AI optimization of workflow dynamics of patient care related information focuses on better management of effort, time, and accuracy. With the advent of AI and cloud technologies, it is becoming technically feasible to store and access patient data in secure cloud storage. Patient data can be easily accessed by multiple providers also located in remote locations. Patient data consists of administrative data and medical data. The administrative data includes data fields like name, date of birth, gender, address, insurance, facility name, and referring physician information. The medical data can include images, scans, and medical reports. For each patient for every medical procedure, numerous documents need to be created, stored, accessed, read, verified, edited, and approved as it works through the medical system. The manual system of managing these documents is inefficient and prone to human error and inaccuracies.

Concerning MRI DICOM data management, the authors' commercialization of AI imaging processing technology (Multus Medical, Inc., Phoenix AZ, USA)

CHAPTER 5

Postoperative Management of Sequelae, Complications, and Readmissions Following Outpatient Transforaminal Lumbar Endoscopy

Kai-Uwe Lewandrowski[1,2,3,*], **Jorge Felipe Ramírez León**[4], **Álvaro Dowling**[5], **Stefan Hellinger**[6], **Nicholas A Ransom**[7] and **Anthony Yeung**[8]

[1] *Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson AZ, USA*

[2] *Associate Professor of Orthopaedic Surgery, Universidad Colsanitas, Bogota, Colombia, USA*

[3] *Visiting Professor, Department Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil*

[4] *Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, Research Team, Centro de Columna, Bogotá, Colombia, USA*

[5] *Centro de Cirugía de Mínima Invasión, CECIMIN - Clínica Reina Sofía, Bogotá, Colombia, USA*

[6] *Department of Orthopedic Surgery, Arabellaklinik,, Munich, Germany*

[7] *Orthopaedic Spine Surgeon, Director of Endoscopic Spine Clinic, Santiago, Chile*

[8] *Clinical Professor, University of New Mexico School of Medicine, Albuquerque, New Mexico Desert Institute for Spine Care, Phoenix, AZ, USA*

Abstract: Best management practices of complications resulting from outpatient transforaminal endoscopic decompression surgery for lumbar foraminal and lateral recess stenosis are not established. Recent advances in surgical techniques allow for endoscopically assisted bony decompression for neurogenic claudication symptoms due to spinal stenosis. These broadened indications also produced a higher incidence of postoperative complications ranging from dural tears, recurrent disc herniations, nerve root injuries, foot drop, facet and pedicle fractures, or infections. Postoperative sequelae such as dysesthetic leg pain, and infiltration of the surgical access and spinal canal with irrigation fluid causing spinal headaches and painful wound swelling, as well as failure to cure, are additional common postoperative problems that can lead to hospital readmissions and contribute to lower patient satisfaction with the procedure. In this chapter, the authors focus on analyzing the incidence of such problems and, more importantly, how to manage them. While the incidence of these problems is recogniz-

* **Corresponding author Kai-Uwe Lewandrowski:** Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson, AZ, USA, Department of Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil and Department of Orthoapedic Surgery, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA; Tel: +1 520 204-1495; Fax: +1 623 218-1215; E-mail: business@tucsonspine.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

ably low, knowing the art of managing them in the postoperative recovery period can make the difference between a flourishing endoscopic outpatient spinal surgery program and one that will continue to struggle with replacing traditional open spinal surgeries.

Keywords: Lumbar endoscopy, Transforaminal decompression, Complications, Sequelae, Postoperative management.

INTRODUCTION

Endoscopy is on the verge of becoming mainstream in spinal surgery. The advantages are increasingly recognized by patients who have the internet at their fingertips and can readily find centers of excellence where innovative surgeons are pushing the envelope of technology applications in spine surgery. Besides the many immediate advantages such as less approach-related access trauma and reduced surgical pain, and diminished need for narcotic pain killers postoperatively, there are many other long-term advantages of staged context-driven endoscopic spine care where only validated predominant pain generators are being treated while ignoring many potential others. This trend away from image-based medical necessity criteria for surgical intervention deemphasizing correction of spinal malalignment, instability, and deformity not only creates the need to redefine the preoperative patient selection criteria, surgical indications, and treatments but also the postoperative management protocols.

Endoscopic spine surgery is fundamentally different from open spine surgery and many other forms of minimally invasive spine surgery. Many of the common problems that steer numerous patients away from open spine surgery, including infections, need for repeat and additional surgeries, complications from scarring, and surgical injury to the neural structures are by far less frequent with endoscopic spine surgery. In contrast, other sequelae and complications specific to endoscopic spine surgery are relevant. Not every spine surgeon is familiar with them, and perhaps even less so with how to manage them. While there is a dedicated chapter in this Bentham text series on the specific surgical complications with the endoscopic spinal surgery both in the cervical and lumbar spine, in this chapter, the authors are describing their clinical experience with their postoperative management of common problems one should be ready to encounter in their busy endoscopic spine practice. While there is no question that the long-term advantages of the endoscopic spine surgery outweigh the short-term problems, patient satisfaction may be negatively impacted if complications such as dural tears, nerve root injury, foot drop, and other sequelae including spinal headaches, dysesthesia, sensory changes, temporary motor weakness, and impaired proprioception are poorly managed during the postoperative recovery period. A recent study suggested that unavoidable side-effects from an expertly executed endoscopic spine surgery defined as sequelae are much more common than actual complications. Nearly a quarter of patients who undergo endoscopic surgery of the lumbar spine may encounter sequela-type problems during the postoperative recovery. Therefore, a text on endoscopic spinal surgery would not be complete unless these issues are openly discussed, and their management debated. This is the purpose of this chapter.

THE REFERENCE STANDARDS

The complication rates with endoscopic spinal surgery need to be discussed in comparison to established rates with the gold stand procedure – the microdiscectomy operation. Contrary to common perception, the complication rates reported in the literature for open and other forms of minimally invasive surgery are higher than one would expect. Nonetheless, they are the reference standard for comparison to endoscopic surgery (Table **1**).

Table 1. Common complications and their incidence reported with microdiscectomy [1 - 5].

Complication(s)	Rate
Dural tears	3%–4%
Cerebrospinal fistula	0.1%
Wrong level surgery	1.2%–3.3%
Wound infections	2%–3%
Spondylodiscitis	< 1%6
Significant blood loss	5%
Nerve root damage ranging from sensory dysfunction to loss of motor strength (foot drop)	0.3%
Life-threatening retroperitoneal vascular lesion	0.05%
Epidural hematoma with new neurological deficits	0.1%–0.2%
Deep venous thrombosis (DVT) even under chemical thromboprophylaxis	2.2%
Persistent leg pain after adequate decompression due to intraoperative nerve root manipulation causing Neurapraxia for days to weeks	2% [11]

What is evident from this literature review is that complications with the gold standard operation are not that uncommon and occur at an incidence between 0.1% to 5%. In the following, the authors intend to review the comparable complication rates and the incidence of unavoidable side effects of well-executed surgeries – sequelae.

CHAPTER 6

Laser Applications in Full Endoscopy of the Spine

Stefan Hellinger[1,*], Anthony Yeung[2,*], Friedrich Tieber[3], Paulo Sérgio Teixeira de Carvalho[4], André Luiz Calderaro[5] and **Kai-Uwe Lewandrowski[6,7,8]**

[1] *Department of Orthopedic Surgery, Arabellaklinik, Munich, Germany*

[2] *Clinical Professor, University of New Mexico School of Medicine, Albuquerque, New Mexico Desert Institute for Spine Care, Phoenix, AZ, USA*

[3] *Medical Technologies Consulting, Augsburg, Germany*

[4] *Department of Neurosurgery, Universidade Federal do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*

[5] *Centro Ortopedico Valqueire, Departamento de Full Endoscopia da Coluna Vertebral, Rio de Janeiro, Brazil*

[6] *Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson AZ, USA*

[7] *Associate Professor of Orthopaedic Surgery, Universidad Colsanitas, Bogota, Colombia, USA*

[8] *Visiting Professor, Department Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil*

Abstract: Lasers have been popular in spine surgery for decades. Patients frequently ask about laser spine surgery when looking for simplified ways to treat spine pain related to a herniated disc. Percutaneous interventional non-visualized needle-based laser treatments have been replaced with visualized endoscopic decompressions. This chapter reviews the fundamental physics of laser technology applications in spine surgery. Guidelines for safe laser use in the operating room and avoidance of complications are discussed in detail. Lasers suitable for spinal decompressions and their respective tissue interactions are described. The clinical evidence of percutaneous *versus* the hybridized use with the visualized endoscopic decompression is examined in detail.

Keywords: Clinical evidence, Endoscopic discectomy, Hybrid laser endoscopic surgery, Laser decompression.

* **Corresponding authors Stefan Hellinger and Anthony Yeung:** Department of Orthopedic Surgery, Arabellaklinik, Munich, Germany and Clinical Professor, University of New Mexico School of Medicine, Albuquerque, New Mexico Desert Institute for Spine Care, Phoenix, AZ, USA; Tel: +1 602 944 2900; E-mails: hellinger@gmx.de, ayeung@sciatica.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

INTRODUCTION

Albert Einstein, in 1917, first postulated that controlled radiation could be obtained from an atom under certain conditions [1]. The term laser is an acronym. Spelled out, it stands for Light Amplification by the Stimulated Emission of Radiation, which describes the process by which photonic energy is harnessed for useful applications. Lasers may be classified by the material - called the medium - used to produce the laser light. Solid-state, gas, liquid, and semiconductor are all common types of lasers. The medium undergoes an excitation process resulting in a population inversion of photons necessary to produce laser light. The majority of surgical lasers fall in the invisible portion of the electromagnetic radiation spectrum. A coaxial aligned, non-therapeutic aiming beam, typically Helium-Neon (532nm), indicates where the laser energy will impact tissue upon activation. The absorption characteristic of the medium largely determines the extent of penetration in particular tissue types. The application of any laser requires the surgeon to thoroughly understand the specific laser's characteristics for safe and effective use. Lasers have always been very attractive with an overall favorable public perception (Fig. **1**). The public's interest in laser spine care far exceeds its interest in minimally invasive-, endoscopic or laser spine surgery (Fig. **2**). Patients and surgeons are seemingly fascinated with the idea of laser care for common painful spinal conditions. However, there may be a gap between perception and understanding of actual laser protocols.

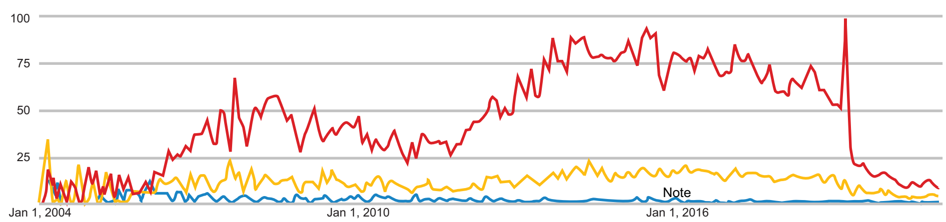

Fig. (1). Graphic depiction of worldwide monthly Google search popularity rating on on "laser discectomy" (blue), "laser spine surgery" (yellow), and "laser spine" (red) from 2004 to the present (data extracted on 12 15 2020). The highest popularity rating of monthly google searches is 100. Therefore, the numbers do not represent actual searches. The public interest in any type of laser treatment is much higher than in laser surgery or discectomy.

Surgeons have long shown an interest in incorporating lasers into minimally invasive spinal surgery procedures. This was first demonstrated by Peter Ascher, who employed neodymium:yttrium-aluminum-garnet (Nd: YAG) laser through an 18 gauge needle introduced fluoroscopically into the intervertebral disc [2]. He ablated the intervertebral disc in a short burst to minimize the heat spread to other adjacent tissues. He vaporized tissue that was allowed to escape through the needle. This procedure was ideally suitable for an outpatient setting as the patient was discharged once the needle is withdrawn in the puncture wound was covered with a small Band-Aid.

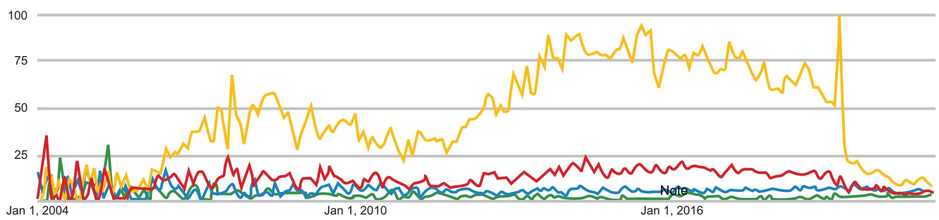

Fig. (2). Graphic depiction of worldwide monthly Google search popularity rating on “minimally invasive spinal surgery” (blue), “laser spine surgery” (red), endoscopic spine surgery (green) and “laser spine” (yellow) from 2004 to the present (data extracted on 12 15 2020). The highest popularity rating of monthly google searches is 100. Therefore, the numbers do not represent actual searches. However, it is evident that the public interest in any type of laser treatment is much higher than in minimally invasive, endoscopic-, and laser spine surgery again illustrating the laser's appeal to the public.

BASIC PHYSICS OF LASERS

The laser was invented in 1958 by Charles H. Townes and Arthur L. Schawlow [1]. They were attempting to create a device for studying molecular structure. They extended research from microwaves to the infrared region of the spectrum and utilized a series of mirrors to focus these shorter wavelengths. In 1960, a patent was granted for the laser. Townes won a Nobel Prize in Physics in 1964 and Schawlow in 1981. Light can be amplified and focused into a very intense beam. The light can be of different wavelengths and is classified as ultraviolet (UV) (150–400 nm), visible (390–700 nm), or infrared (greater than 700 nm) as part of the electromagnetic spectrum.

Atoms at their resting or ground state can be excited to a higher energy level when they absorb electrical, optical, or thermal energy. When the atom returns to its preexcitation state, it releases energy as a photon. This occurs naturally and spontaneously. Emission of two photons of the same frequency occurs if the atom is hit with another photon while on its descent from the excited state to the ground state. This happens in phase (coherence) with and in the same direction as the bombarding photon. This process is called stimulated emission. When these photons stimulate enough atoms to create a population inversion where there are more atoms in the excited stage than the ground state, a powerful coherent beam of energy is produced and emitted radiation (Fig. **3**).

CHAPTER 7

High Frequency Surgery for the Treatment of Herniated Discs

Friedrich Tieber[1], **Stefan Hellinger**[2,*], **Hyeun-Sung Kim**[3] and **Kai-Uwe Lewandrowski**[4,5,6]

[1] *Medical Technologies Consulting, Augsburg, Germany*

[2] *Department of Orthopedic Surgery, Arabellaklinik, Germany*

[3] *Nanoori Hospital, Nonhyeon-dong, Gangnam-gu, Seoul, South Korea*

[4] *Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson AZ, USA*

[5] *Department of Orthopaedic Surgery, Universidad Colsanitas, Bogota, Colombia, USA*

[6] *Visiting Professor, Department Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil*

Abstract: High-frequency coagulation, cutting, and coblation technology have long been applied during endoscopic spine surgery. Endoscopic visualization devices and high-frequency surgical devices can be found in almost every surgical subspecialty. During surgical HF applications, electrical energy is converted into heat, used to cut biological tissue and stop bleeding. This technology works with high voltages in cutting and coagulation mode. The difference is in the creation of arcs, which have a cutting effect. In simplified terms, voltages of ≤ 200 Volts are generated during coagulation and > 200 Volts during cutting. The interaction of HF with biological tissue can be explained by the faradic, electrolytic, and thermal effect. A frequency of over 400 kHz has no harmful effect on body tissue. Frequencies over 1MHz have a "cold cutting effect" allowing for safe bipolar applications and minimizing thermal damage. This chapter reviews how modern high-frequency generators work and how to minimize risk during clinical applications, including electrode bonding and burns by applying automatic power metering, two-part neutral electrode, and bipolar techniques. During spinal endoscopy, the effects of HF treatment can be directly assessed under very high magnification factors. This complementary overlap of the videoendoscopic and HF technique in modern endoscopic spine surgery is the key to superior clinical outcomes compared to non-visualized percutaneous procedures performed under fluoroscopic control.

Keywords: Coblation, Cutting, Endoscopic surgery, Herniated disc, High frequency.

[*] **Corresponding author Stefan Hellinger:** Department of Orthopedic Surgery, Arabellaklinik, Germany; Tel: +1 520 204-1495; Fax: +1 623 218-1215; E-mail: hellinger@gmx.de

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

INTRODUCTION

The trend in minimally invasive spine treatment of axial discogenic pain non-responsive to conservative treatment methods continues to expand throughout the medical community worldwide. With this minimalist evolution, techniques and technologies have progressed to permit atraumatic access, preserve anatomy, maintain the viability of endplates, and minimize scar tissue formation with overall reduced tissue incision, dissection, and manipulation. Surgeons are faced with an array of accessory devices, primarily energy-based technologies, to facilitate soft tissue access, preparation, and tissue modulation.

The use of thermal energy to modulate and ablate tissue is not new. In one form or another, electrical current has been applied to human tissues as a surgical modality for over 100 years. Modern electrosurgery traces its roots to Doyen's machines in the 1920s and Bovie in the 1930s. Electrosurgical units generally operate from 200 to 500 kHz. Devices operating in this frequency range cause the electrode that comes in contact with the tissue to become hot, therefore acting like true heat cautery. In the 1950s, Malis invented a spark gap machine consisting of a bipolar generator and forceps designed to control lateral heat spread to adjacent tissues.

High frequency (HF) surgery for the treatment of herniated discs and spinal endoscopy are complementary procedures. Galvano- and diathermy surgery are twins of the modern HF treatments and have been used since the middle of the 19th century. It was the beginning of the 20th century when Erbe developed HF surgical devices in Europe and Bowie in the USA. Endoscopic visualization devices and high-frequency surgical devices can be found in almost every operating theater globally, both of which are used in all surgical disciplines, both in a hospital and ambulatory surgery setting. In high-frequency surgery, HF alternating current is passed through the human body to achieve targeted hemostasis and sever through the tissue heating it causes in monopolar applications.

Generators with a maximum power of 400 Watts are usually used for HF electrosurgery. The output voltage can be a high voltage of up to 4 kilovolts (kV) when idling. In dentistry and ophthalmology, weaker devices with maximum outputs of 50 Watts with lower voltages are common. The generators on the market usually allow different operating modes. This includes cutting and coagulation. The difference is in the creation of arcs which have a cutting effect. In simplified terms, it can be said that generator voltages of ≤ 200 Volts are generated during coagulation. In cutting mode, the voltages are greater than 200 Volts.

DIFFERENTIATION BETWEEN RF, HIGH RF AND RADIO WAVES

All these descriptions are synonymous with high-frequency (HF) waves. There is no difference between the radiofrequency (RF) and radio wave (RW). In European literature, they are called high-frequency waves. In the North American literature, the term radiofrequency is preferred. The typical range for medical applications is between 3 and 300 MHZ. Waves above this range are called High RF.

GENERAL ASPECTS OF HF SURGERY

Electrosurgery and Radiofrequency energy occupy a range upon the Electromagnetic Radiation Spectrum. The frequency at which the device operates will determine the absorption characteristics, tissue effects, and surgical utility, much like the medium of a laser. Standard monopolar or bipolar devices emitting frequencies under 500kHz are limitedly applied or avoided by the energy source savvy clinician to prevent unwanted tissue destruction. Control of penetration and target tissue effects have led to an interest in various electrosurgical devices and delivery systems. One must realize that the frequency with which the device operates mainly dictates the unique properties and capabilities or limitations of the technology.

High-frequency or radiofrequency in the frequency range between 1.7MHz and 4.0MHz of the radiation spectrum emits energy that is non-thermal with absorption characteristics of water-rich tissues. Transferred from the long-term use in ocular plastics, reconstructive and neurosurgical fields, the frequencies of 1.7 and 4.0Mhz have been reported to be optimal for controlled absorption with minimal tissue alteration. The spine and neurosurgical communities are widely accepting radio-wave technology for the cell-specific precision it affords which played out favorably in endoscopic spine surgery. The demands of critical-anatomy-based surgery warranting precision make this specific technology attractive and a compliment to the equipment armamentarium.

With electrical energy converted into heat, one can cut biological tissue and stop bleeding. Since this technology works with high voltages, there are certain risks. In order to minimize them, it is crucial to be aware of how the technology works. The higher the current density, the greater the temperature increase and the damaging thermal effect. The current density increases at the tip of the monopolar electrocautery - the active electrode. An arc is formed, leading to a very high temperature locally with which tissue can be cut or obliterated. In contrast, at the neutral electrode's - typically a large surface - the current density and temperature development are so low that no harmful effect occurs. The electric current's inter-

CHAPTER 8

Lumbar MRI– How Useful is It in Surgical Decision Making for Spinal Endoscopy?

Kai-Uwe Lewandrowski[1,2,3,*], **Stefan Hellinger**[4], **Paulo de Carvalho**[5], **Max Rogério Freitas Ramos**[6,7] and **Jorge Felipe Ramírez León**[8]

[1] *Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson AZ, USA*

[2] *Associate Professor of Orthopaedic Surgery, Universidad Colsanitas, Bogota, Colombia, USA*

[3] *Visiting Professor, Department Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil*

[4] *Department of Orthopedic Surgery, Arabellaklinik,, Munich, Germany*

[5] *Department of Neurosurgery, Universidade Federal do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*

[6] *Associate Professor of Orthopedics and Traumatology, Federal University of the Rio de Janeiro State UNIRIO, Rio de Janeiro - RJ, Brazil*

[7] *Head of Orthopedic Clinics at Gaffrée Guinle University Hospital HUGG, Rio de Janeiro - RJ, Brazil*

[8] *Orthopedic and Minimally Invasive Spine Surgeon; Reina Sofía Clinic and Center of Minimally Invasive Spine Surgery – Bogotá Colombia. Chairman, Spine Surgery Program, Universidad Sanitas, Bogotá, D.C., Colombia, USA*

Abstract: The commonly used preoperative lumbar MRI grading lags behind modern patient selection criteria to prognosticate favorable outcomes with the endoscopic decompression for lumbar herniated disc and foraminal and lateral recess stenosis. Since its utilization has evolved into a primary medical necessity criterion for surgical intervention, surgeons often find themselves with clinical symptoms whose treatment is not supported by the MRI report. Therefore, this chapter's authors established the need to determine the MRI's accuracy and positive predictive value for successful postoperative pain relief after endoscopic transforaminal decompression. Using the transforaminal endoscopic technique, the authors performed a critical retrospective analysis of 1839 patients who had surgery for herniated disc and stenosis in the foramina or lateral spinal canal. They calculated the sensitivity, specificity, accuracy, and positive predictive value of preoperative MRI grading, correctly identifying the

* **Corresponding author Kai-Uwe Lewandrowski:** Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson, AZ, USA, Department of Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil and Department of Orthoapedic Surgery, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA; Tel: +1 520 204-1495; Fax: +1 623 218-1215; E-mail: business@tucsonspine.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

symptomatic surgical level by correlating it with the directly visualized pathology during surgery and clinical improvements. The lumbar MRI verbal report's sensitivity was calculated at 68.34%, the specificity at 68.29%, the accuracy at 68.24%, and the positive predictive value at 97.38%. The use of surgical MRI criteria for nerve compression detailed within this manuscript improved the calculated sensitivity to 87.2%, specificity to 73.03%, and accuracy to 86.51%. The likely explanation lies in the lack of consensus between radiologists and spine surgeons when grading compression syndromes of the exiting and traversing nerve root. The grading of a preoperative MRI scan for lumbar foraminal and lateral recess stenosis may significantly differ between radiologists and surgeons. The authors conclude that the endoscopic spine surgeon should read and grade the lumbar MRI scan independently.

Keywords: Lumbar endoscopic transforaminal decompression, Preoperative MRI scan.

INTRODUCTION

Magnetic resonance imaging (MRI) is commonly used to evaluate patients with sciatica-type low back and leg pain [1]. Frequently, MRI suggests multilevel degeneration with disc herniations, facet hypertrophy, and stenosis but should they be interpreted as causes of sciatica-type back and leg pain? What is the predictive value of MRI findings in prompting interventional or surgical care? Unfortunately, the answer is unclear. MRI is integral to the preoperative workup, and its reporting is sometimes the only means insurance companies use to determine the medical necessity of surgical decompression of spinal stenosis. MRI reporting has also become the primary means of communicating the severity of the patient's lumbar degenerative disease among the stakeholders involved in patient care to document the location and extent of lumbar spinal decompression needed to treat the patient's symptoms.

THE PROGNOSTIC VALUE OF THE MRI SCAN

The predictive value of MRI in therapeutic decision-making has been debated [1 - 3]. More than half of the asymptomatic volunteers may have abnormal findings. This number increased between 57% to 80% for those older than 60 years of age [4, 5]. Such MRI abnormalities have been correlated with self-reported pain and appear to have a negligible effect on patient care or outcome [6]. The ultimate gold standard to assess the accuracy of a diagnostic study such as MRI is not another imaging study but direct visualization of pathology during surgery and response to treatment evaluated with clinical outcome studies. Some studies have used surgery as the gold standard to assess lumbar MRI scan accuracy, with some analyses correlating the imaged neural impingement with directly intraoperatively visualized pathology [7 - 13]. Outcome has been employed as another gold standard in assessing lumbar MRI accuracy [14 - 18]. This chapter's focus is simple: What is the predictive value of MRI image-based diagnostic criteria in routine preoperative planning for endoscopic decompression for lumbar spinal stenosis and herniated disc? The authors aimed to analyze the accuracy and positive predictive value (PPV) of a preoperative lumbar MRI grading concerning intraoperatively visualized pathology. They wanted to correlate the visualized pathology with the findings on the preoperative MRI scan, and these MRI findings predicted pain relief with the transforaminal endoscopic lumbar decompression surgery. The accuracy and PPV of MRI reporting in the author's community were calculated and compared to surgeon grading of spinal stenosis using clinical outcome measures and what painful pathology was visualized during the endoscopic surgery.

THE VALUE-BASED SOLUTION

Nowadays, minimally invasive spinal procedures are commonplace [19 - 25]. The volume of these procedures in outpatient surgery centers has disproportionally increased compared to outpatient departments in a hospital setting [26 - 28]. Patients prefer the procedure over open surgery because of much lower complication rates, blood loss, fewer pain killer requirements postoperatively, and faster return to work [29, 30]. The latter problem is significant considering the narcotic epidemic in the United States [31 - 33]. Payors have implemented more front-end scrutiny on the vetting of the medical necessity of spine surgery in general. Some consider endoscopic spine surgery experimental and excluded from coverage as they consider it outside value-based purchasing health care measures. In comparison, some other forms of translaminar minimally invasive spinal surgery have been accepted to serve the aging baby-boomer population [34, 35]. The medical necessity is best explained with a definitive diagnostic workup to make a case for endoscopic spine surgery.

SURGICAL DECISION MAKING

The patients' workup included history, physical examination, plain films, and MRI imaging. Diagnostic transforaminal epidural injections with lidocaine were done preoperatively to validate pain generators amenable to transforaminal endoscopic decompression [36 - 42]. A lidocaine-containing transforaminal diagnostic injection is employed to determine the location of foraminal pain generators. It is confirmed when the patient reports 50% pain relief within 15 minutes of the injection. In conjunction with corroborating findings on the physical examination and the advanced imaging studies, the location of the surgical intervention is most reliably identified [43].

CHAPTER 9

Cost and Maintenance Management of Endoscopic Spine Systems

Friedrich Tieber[1], **Stefan Hellinger**[2] and **Kai-Uwe Lewandrowski**[3,4,5,*]

[1] *Medical Technologies Consulting, Augsburg, Germany*

[2] *Department of Orthopedic Surgery, Arabellaklinik, Munich, Germany*

[3] *Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, 4787 E. Camp Lowell Drive, Tucson AZ 85712, USA*

[4] *Associate Professor, Universidad Sanitas, Bogotá, D.C., Colombia, USA*

[5] *Visiting Professor Department Neurosurgery, UNIRIO, Rio de Janeiro, Brazil*

Abstract: Successful implementation of endoscopic spinal surgery programs hinges on reliable performance and case cost similar to traditional decompression surgeries of the lumbar spine. Spinal endoscopes used during routine lumbar decompression surgeries for herniated disc and spinal stenosis should have an estimated life cycle between 150 to 300 surgeries. However, actual numbers may be substantially lower. Abusive use by surgeons, mishandling by staff, and deviation from prescribed cleaning and sterilization protocols may substantially shorten the life cycle. Contingency protocols should be in place to readily replace a broken spinal endoscope during surgery. More comprehensive implementation of endoscopic spine surgery techniques will hinge on technology advancements to make these high-tech surgical instruments more resistant to the stress of daily use and abuse of expanded clinical indications' surgery. The regulatory burden on endoscope makers is likely to increase, calling for increased reimbursement for facilities to cover the added expense for capital equipment purchase, disposables, and the cost of the endoscopic spine surgery program's maintenance. In this chapter, the authors review such maintenance programs' cornerstones in the current regulatory environment that one should implement when attempting to run an endoscopic spinal surgery program at their healthcare facility.

Keywords: Equipment Durability, Cost, Maintenance, Regulatory, Spinal endoscopy.

[*] **Corresponding author Kai-Uwe Lewandrowski:** Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson, AZ, USA, Department of Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil and Department of Orthoapedic Surgery, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA; Tel: +1 520 204-1495; Fax: +1 623 218-1215; E-mail: business@tucsonspine.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

INTRODUCTION

A successfully run endoscopic spinal surgery program depends on reliably performing equipment that can hold up to the abuse of a high-volume clinical program.

Moreover, well-trained and trustworthy staff with dependable knowledge of the cleaning and sterile processing procedures is another crucial element in keeping the cost of maintenance and repairs under control. Everyone partaking in the day-to-day routine of such an endoscopic spine surgery program should understand how this highly sensitive and expensive optical and surgical equipment is custom-built, not easily replaceable, and represents an asset of the healthcare facility whose management requires good stewardship. Team members should employ careful handling of these delicate optical instruments through well-established and uninterrupted custody chains, extending to the end-user surgeons. Practitioners may not always understand the limits of a rigid rod-lens system design of modern spinal endoscopes and their performance limits as they attempt to expand clinical indications of the procedure by trying more complex spinal decompression [1] and increasingly fusion [2 - 7] operations.

High-quality spinal endoscopes are the cornerstone of a well-run spinal endoscopy program. The Instruction For Use (IFU) for modern endoscopes made by various vendors frequently lists a range of 150 to 300 cycles that the end-user should be able to expect before repair or replacement is necessary when employing the recommended intraoperative applications, cleaning- and sterilization procedures. Actual performance cycles may be substantially lower since manufacturers cannot predict actual use patterns by the end-user. Acceptance of surgeons who try to implement endoscopic spinal surgery programs at their respective healthcare facilities may be delayed because of the high implementation cost for capital purchases. It could be further negatively impacted when higher case numbers expose the technology's shortcomings due to added cost for disposables and repairs. Administrators of hospitals and surgery centers are facing lower reimbursement for the standard spinal decompression and fusion codes. Therefore, the higher upfront cost to jumpstart a program that replaces these traditional surgeries with lower or unpredictable payment schedules may pose an insurmountable hurdle that could be hard to overcome.

The affordability of the endoscopic technology for spine surgery is a highly complex problem that not only depends on start-up cost but also on the payer base. The latter is difficult to control, but the cost of maintenance and repair is not. In this chapter, the authors are laying out the highlights of managing the maintenance and the associated cost of endoscopic equipment that is routinely used in spinal endoscopic decompression procedures. The aim was to give the readers insight into what is at stake to be easily replicated in their clinical setting.

COST MANAGEMENT OF MEDICAL DEVICES

Anyone who has used a mechanical or technological device knows that devices tend to break down over time. There are few other industries where managing such resources in the operation is more critical than in healthcare. There are many components associated with medical device management that contribute to high life cycle costs. It is estimated that these costs reach about 100 billion dollars annually. For many healthcare delivery players, this is not just a monetary burden but also requires increasing human resource management dedicated to the maintenance and repair of such high-tech equipment to keep the complex clinical programs going.

Life cycle costs consist of Medical Product Investment (MPI), installation costs, service and repair costs for hard- and software components, and proper ongoing use of the entire equipment. Devices with a high level of complexity typically have high installation and maintenance costs associated with them. The more a hospital or health system spends on these processes, the higher the scrutiny on the clinical and fiduciary performance of such high-tech programs as hospitals and surgery centers are already operating on low margins. Administrators of such organizations may hesitate to implement a novel but costly spinal endoscopy program in their facility if they do not understand the revenue cycle of the new proposed surgical procedure and the ongoing cost for running it either due to maintenance and repairs, or disposables and staff training requirements. Responsible industry partners will help the team leaders at the facility calculate reimbursement of the investment for a complete workstation based on accepted surgical indications. There is an existing time-proven reimbursement coding structure in place.

One way to improve return on investment (ROI) is to set up an endoscopic spinal surgery program with multiple surgeons for the same or for a variety of indications for one and the same workstation to minimize downtime. The other side of the equation is operational cost. The design and build quality of a particular piece of equipment go a long way toward determining its propensity for breakdowns and need for repairs. Some of the products of endoscopic sets and workstations include surgical instruments, endoscopes, video towers and power tools. Surgeons have a significant influence on the product's design. They should work closely with the development team including physicists, electronic engineers, and IT specialists, and the OEM manufacturer and the entity that pro-

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CHAPTER 10

Regenerative Medicine and Interventional Endoscopic Pain Surgery for Degenerative Conditions of the Spine

Álvaro Dowling[1], **Juan Carlos Vera**[2] and **Kai-Uwe Lewandrowski**[3,4,5,*]

[1] *Orthopaedic Spine Surgeon, Director of Endoscopic Spine Clinic, Santiago, Chile. Visiting Professor, Department of Orthopaedic Surgery, USP, Ribeirão Preto, Brazil*

[2] *Molecular Biotechnology Engineer, Universidad de Chile Business Development Manager-VidaCel, Chile*

[3] *Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson AZ, USA*

[4] *Associate Professor of Orthopaedic Surgery, Universidad Colsanitas, Bogota, Colombia, USA*

[5] *Visiting Professor, Department Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil*

Abstract: Regenerative medicine is a subspecialty of medicine that seeks to recruit and enhance the body's own inherent healing armamentarium in the treatment of patient pathology. In regenerative spine care, the intention is to assist in the repair and potentially replace or restore damaged tissue through autologous or allogenic biologics. In the authors' opinion, future spine care will likely evolve into a blend of prevailing strategies from interventional pain management and minimally invasive spine surgery. This form of spine care nowadays is commonly called interventional pain surgery. The interest in regenerative medicine in general and in interventional pain surgery of the spine is growing given the high patient awareness of problems with traditional spine surgery, whose focus is on decompression of pinched nerves and correction of spinal instability and deformity. However, reoperation- and complication rates are high with those open corrective spine surgeries as many of the spine's degenerative conditions are being only treated surgically when the disease has progressed to its end-stage. The sole application of image-based medical necessity criteria for surgical intervention in the spine seems slightly out of step with the growing demand for less aggressive and burdensome procedures that could perhaps be instituted earlier in the disease process where the goal is to heal the spinal injury or repair damage from the degenerative process more naturally. In this chapter, the authors review and discuss the current state of the art in regenerative biologic therapies and interventional pain care of the

* **Corresponding author Kai-Uwe Lewandrowski:** Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson, AZ, USA, Department of Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil and Department of Orthoapedic Surgery, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA; Tel: +1 520 204-1495; Fax: +1 623 218-1215; E-mail: business@tucsonspine.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

spine from their perspective as endoscopic spine surgeons. Simplifying therapeutic measures and strategies are at the heart of what patients request of us as surgeons. This field's applications in modern spine care are clearly in their infancy, except for fusion. The authors will discuss potential applications of select advanced biologics technologies and their attempts at integrating them into their endoscopic spinal stenosis surgery program to treat degenerative spinal disease and instability-related symptomatic end-stage degenerative vacuum disc disease in the elderly.

Keywords: Biologics, Endoscopic spine care, Regenerative technologies.

INTRODUCTION

Numerous treatments and therapeutics have been applied to manage chronic spinal pain ranging from over the counter medications and devices, a variety of image-guided interventional pain management techniques, to complex spinal fusion. The emerging field of regenerative medicine is likely to become the next frontier in musculoskeletal and spinal care models [1 - 3]. According to the recent statistics, Americans already spent some 87.6 billion on self-directed management of low back and neck pain and another 95.9 billion on musculoskeletal pain. These numbers account for the third and fourth highest health care expenditure among all disease categories.

Despite numerous alternative therapy techniques to spinal fusion, this aggressive and disruptive way of treating common degenerative conditions of the lumbar spine remains the mainstay of modern spine care. Although clinical outcomes with spinal fusion are well studied and its indications well understood, it remains riddled with blood loss, persistent postoperative pain, a relatively high complication- and reoperation rate due to adjacent segment disease, and junctional instability and deformity. The stigma of overall high cost and continued medical service utilization even after extensive surgery, persistent disability, and low return-to-work rates remain. Evidence-based clinical treatment guidelines published by several professional organizations have attempted to outline appropriate medical necessity guidelines for surgical spine care to achieve more consistent clinical improvements in a more cost-effective manner. However, such medical societies' clinical treatment- or insurance companies' coverage guidelines may also hamper innovation. Nowadays, regenerative medicine is still a stepchild of spine care and is often declared experimental. It is typically only made available to those who can afford it. Success stories of such regenerative therapies in professional athletes will likely facilitate bringing it to the forefront of accepted medical care by incorporating biomechanical, biochemical, biomedical technology advancements to improve cellular replication migration, restitution, and modelling [4 - 11].

While there is no doubt that regenerative medicine will play an increasing role in modern spine care, the burden of proof will always rest on the innovators. Desperate patients, sometimes driven by media hype, will always seek out promising treatments even if the clinical evidence in their support is weak. Therefore, adherence to the highest ethical standards in any other medical research area is the foundation for conducting clinical outcome research with commonly pursued regenerative therapeutic strategies, including medicinal signaling, mesenchymal- and stem cells [12] and platelet-enriched plasma [13 - 16] injections. Injections of these remedies in facet joints and discs [3, 12, 14, 17] of the lumbar spine and the sacroiliac joints [18, 19] and paraspinal muscles [20], ligaments [16, 21, 22], and tendons [23 - 25] have been tried. This chapter will review the current state-of-the-art regenerative therapies of the intervertebral disc and enhancement of interbody fusion as they apply to endoscopic spine surgery. Regarding the latter, the authors present their clinical experience with platelet enriched application allograft corticocancellous chips in un-instrumented spinal fusions intended for the elderly as one example of simplified spine care.

REGENERATIVE MEDICINE STRATEGIES

Biological therapies help heal tissues damaged acutely or chronically, including ligaments, menisci, articular cartilage, tendons, discs, and joints. While various biologicals are utilized in regenerative therapy of the spine and other musculoskeletal disorders, platelet rich plasma (PRP) and mesenchymal stem cells (MSCs) are the current mainstays of regenerative medicine treatments.

Platelet Rich Plasma

PRP's regenerative benefits occur *via* the increased concentration of growth factors secreted by platelets in an inflammatory environment [26]. It may be derived from autologous or allogeneic derivatives of whole blood and contains very high concentrations of platelets. These growth factors are essential to the healing process, as they increase fibroblast and osteoblast metabolic activity while reducing cell apoptosis. They are promoting angiogenesis, thereby increasing blood flow and circulation to the newly formed tissues and increasing the expression of the pro-collagen gene and collagen-derived growth factors, which increase the tensile strength of the new tissue (Fig. **1**) [27 - 29].

The α-granules have been recognized to provide the growth factors and cytokines essential to normal wound healing [30]. PRP derived factors play a role in local angiogenesis, proliferation, differentiation, and homing of local and stem cells. They also are responsible for local production of matrix proteins, including collagen, which are the building blocks of normal tissue restoration. The net effect on the local tissue environment is regeneration. Exciting its regenerative effects

CHAPTER 11

Transforaminal Epiduroscopic Basivertebral Nerve Laser Ablation for Chronic Low Back Pain Associated with Modic Changes

Byapak Paudel[1, 2], **Nitin Maruti Adsul**[1,3], **Hyeun Sung Kim**[1,*] and **Il-Tae Jang**[1]

[1] *Department of Neurosurgery, Nanoori Gangnam Hospital, Seoul, Republic of Korea*

[2] *Department of Orthopaedics & Traumatology, Grande International Hospital, Kathmandu, Nepal*

[3] *Sir Ganga Ram Hospital, Ortho-Spine Surgery, New Delhi, India*

Abstract: Among different causes of chronic low back pain, Modic changes of the endplates have been identified as an MRI-image representation of end stage degenerative disc disease. Painful innervation of these degenerative endplates from within the vertebral body by arborization of the basivertebral nerve towards these endplates has been demonstrated. Ablation of the basivertebral nerve has been identified as one possible way to treat chronic low back pain. This chapter describes the transforaminal epiduroscopic laser ablation of the basivertebral nerve and its associated clinical outcomes.

Keywords: Basivertebral nerve, Chronic low back pain, Epiduroscopy, Laser ablation, Modic changes, Transforaminal approach.

INTRODUCTION

Chronic back pain is a disabling condition affecting large portions of the aging population the world over. It is associated with decreased quality of life and loss of economic status. Pain in the spine may arise from any of the three columns. Pain in the anterior column may be from discal pressure changes and is commonly referred to as discogenic low back pain. Stimulation of neural structures around the disc and vertebral endplate and symptomatic disc degeneration in the middle column in conjunction with chemical changes and mechanical pressure on the neural structures are leading pain generators in the middle column. Similarly, pain in the posterior column may arise in facet joints, muscles, and ligaments.

[*] **Corresponding author Hyeun Sung Kim:** Department of Neurosurgery, Nanoori Gangnam Hospital, Seoul, Republic of Korea; Tel: +82-10-2440-2631; E-mail: neurospinekim@gmail.com

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These conditions may cause axial back pain with or without radiation along recognized dermatomes. It can also cause referred pain – the so-called sclerotomal pain, which patients may describe as local or referred deep-seated bone pain referred from degenerated vertebral segments.

Modic changes of the degenerated vertebral endplates have been associated with an MRI-image correlated with such sclerotomal pain [1]. There are three types of Modic changes [2]. In type one, the T1-weighted image series shows a hypointensity signal, and T2 weighted images show a hyperintensity signal in the endplates. These findings are believed to be structurally related to acute disruption and fissuring of endplates. This condition leads to vascularized fibrous tissue's ingrowth into the marrow of the corresponding adjacent vertebral body. Type two Modic changes represent chronic degeneration, and the MRI image correlates hyperintensity in T1- and isointensity in T2-weighted series. Histologically there is the fatty degeneration of the vertebral bone marrow. Type three Modic changes represent bony sclerosis. Its MRI image correlate shows hypointense T1- and T2-weighted image series. Modic changes are associated with chronic low back pain [3]. Especially, type 1 and 2 Modic changes have been identified as most painful [4, 5].

A painful symptomatic lumbar motion segment may be the sensitized ingrowth of nerve fibers from the sinuvertebral- and the basivertebral nerve. The sinuvertebral nerve is densely located at the posterior annulus and posterior longitudinal ligament, whereas the basivertebral nerve preferentially innervates the endplates. (6) Therefore, the authors stipulated that the transforaminal epiduroscopic laser ablation of the basivertebral nerve may be a viable alternative to more aggressive spinal surgeries, including fusion to treat chronic back pain associated.

THE RATIONALE OF TRANSFORAMINAL LASER ABLATION OF THE BASIVERTEBRAL NERVE

The vertebral endplate is richly innervated by free nerve endings that arborize the basivertebral nerve. This neoinnervation may be sensitized and stimulated by inflammatory mediators. When the basivertebral nerve is sensitized, it may produce disabling chronic low back pain. Pain may be associated with or without Modic changes. Conceptionally, the ablation of the basivertebral nerve disrupts nociceptors' signal path, thereby producing pain relief (Fig. **1**).

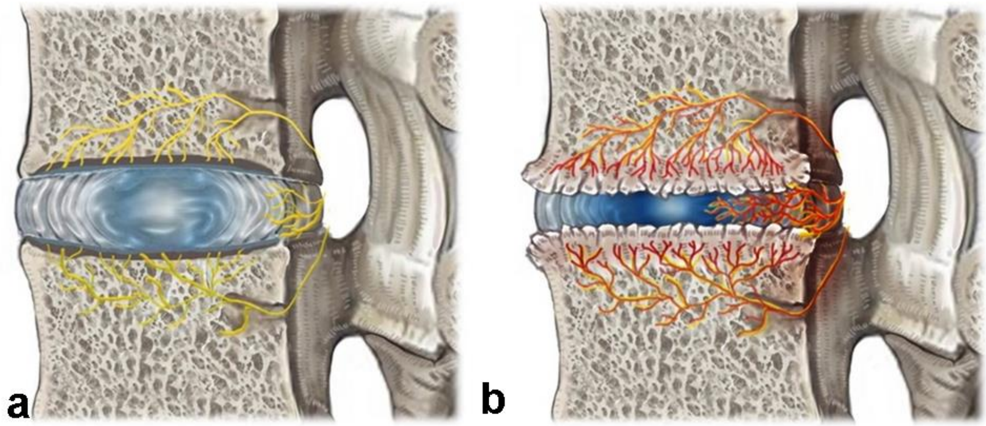

Fig. (1). Illustration of pathologic innervation of degenerative endplates by the basivertebral nerve: **a)** normal innervation, **b)** pathologic innervation.

SURGICAL SETUP

The transforaminal laser ablation of the basivertebral nerve is indicated in patients with severe low back pain associated with positive discography. Other etiologies should be ruled out with clinical investigations, including advanced CT or MRI imaging and diagnostic spinal injections. After diagnostic confirmation of discogenic low back pain associated with end-stage degenerative disc disease with Modic changes of the endplates on MRI scanning, patients may consent for the interventional surgical basivertebral nerve ablation. The authors developed a clinical protocol consisting of directly visualized transforaminal endoscopic laser ablation of the basivertebral nerve. The transforaminal endoscopy platform lends itself well for the epiduroscopic laser ablation as it provides easy access to the epidural space surrounding the disc space. The epiduroscopic laser ablation technology uses a small flexible epiduroscopic catheter system through which the laser fiber can be introduced and directed under continued direct visualization onto the basivertebral nerve. Therefore, this hybrid procedure requires that the surgeon understand both the transforaminal endoscopic anatomy and the technical and procedural aspects of spinal endoscopic and epiduroscopic procedures. Characteristics of patient positioning OR setup, incision access planning by identifying surgical landmarks. The docking points at the spine for the endoscopic working cannula have been described in other chapters of this Bentham text series on spinal endoscopy. The authors also emphasize the need for high-quality endoscopes, endoscopic instruments, and videoendoscopic tower systems to support this delicate detail-driven operation.

CHAPTER 12

Uniportal Endoscopic Transforaminal Decompression Associated with Cylindrical Percutaneous Interspinous Spacer

R. Cantú-Leal[1,*] and **R. Cantu-Longoria**[2]

[1] *Department of Spine Surgery, Hospital Christus Muguerza Alta Especialidad in Monterrey, Mexico*

[2] *Orthopaedic Spine Surgeon, Hospital Christus Muguerza Alta Especialidad, Villa Alegre C.P. 64130 Monterrey. N.L., Mexico*

Abstract: Combining the percutaneous transforaminal endoscopic decompression (PTED) with interspinous process distraction systems (ISP) may offer additional benefits in treating spinal stenosis in patients who have failed conservative treatment. We retrospectively investigated the medical records of 152 patients who underwent transforaminal endoscopic decompression with simultaneous ISP placement through the same incision. Patients were operated on from January 2008 to June 2016 and included 80 males, and 72 patients were females. Clinical data analysis was done on 142 patients two years postoperatively since ten patients were lost in follow-up. Primary outcome measures were pre-and postoperative visual analog scale (VAS) criteria and the Oswestry Disability Index. Only patients with a minimum follow-up of 2 years were included. The analysis included 224 patients who underwent interspinous spacers during the transforaminal endoscopic decompression. Of the 152 patients, 84 complained of axial facet-related pain syndromes *versus* the remaining 68 patients who chiefly complained of radicular symptoms. The postoperative VAS reduction at two-year follow-up for the low back was 6.4. The patient-reported ODI reductions were of a similar magnitude at 40.4%. According to Macnab criteria, the percentage of patients who graded their surgical results as excellent or good was 90%. At two-year follow-up, 5 percent of patients required another operation to deal with failure to cure or recurrent symptoms due to implant subsidence. The authors concluded that adding an interspinous process spacer to the endoscopic decompression in patients treated for lateral lumbar stenosis and foraminal stenosis with low-grade spondylolisthesis might improve clinical outcomes by stabilizing the posterior column.

Keywords: Endoscopic spine surgery, Interspinous process distraction, Lumbar lateral recess and foraminal stenosis.

* **Corresponding author R. Cantú-Leal:** Department of Spine Surgery, Hospital Christus Muguerza Alta Especialidad, Monterrey, Mexico; Tel: +52 81 8333 1216; E-mail: dr_robertocantu@yahoo.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

INTRODUCTION

The authors of this chapter explored the feasibility and clinical benefits of a transforaminal decompression procedure combined with a percutaneous threaded cylindrical interspinous process spacer placed through the same lateral portal for better relief of both radicular leg and axial back pain symptoms stemming from the resulting decrease in the remaining nucleus pulposus and decreased pressure on arthritic facet joints. The authors are well-recognized key opinion leaders (KOLs) known for having pioneered endoscopic spinal surgery in Mexico, starting in an academic hospital-based setting with an orthopaedic residency program over 20 years ago. The endoscopic spine surgery program began with simple transforaminal decompression surgeries employing the “inside-out” technique popularized by Yeung *et al*. in the late 1990ies [1 - 5]. The authors soon realized that the transforaminal discectomy effectively relieves sciatica-type leg- and back pain but had limitations. That definition of appropriate patient selection criteria was directly related to the surgeons’ skill level and the availability of advanced endoscopic equipment. With the evolution of more advanced video-endoscopic equipment and more effective decompression tools, indications for endoscopic spinal surgery have expanded from simple herniated disc to include sciatica stemming from boney or ligamentous stenosis. The latter condition is often associated with more advanced degeneration of the lumbar motion segment involving the facet joint complex and the intervertebral disc itself. Advanced disc degeneration may be associated with increased intradiscal pressures and progressive vertical collapse. In the end-stage of the degenerative process, the intervertebral disc may even be void of any functional tissue and has been reported to be hollow at times. The concept of vertical instability has been introduced by Luk *et al*. to characterize this process [6]. It essentially implies dynamic lateral recess and foraminal stenosis due to a mechanically incompetent disc that others have associated with the vacuum phenomenon [7 - 9]. In the opinion of this team of authors, this process may contribute to less favorable clinical outcomes. It stimulated the interest in combining the endoscopic three transforaminal decompression procedure with other ancillary procedures that could aid in the stabilization of the lumbar motion segment, perhaps earlier in the disease process, without exposing the patient to the burden of a traditional instrumented fusion. Therefore, the idea of combining the endoscopic transforaminal decompression with an interspinous process spacer was entertained.

INTERSPINOUS PROCESS SPACERS

Knowles introduced the first lumbar interspinous process spacer (IPS) in the ‘50s [10]. In the last decade, many ISPs have been marketed. However, only the following implants have been approved by the FDA: X-STOP® Interspinous Process Decompression (IPD®) System, Coflex® Interlaminar Technology implant (formerly known as Interspinous U), and the Superion® Interspinous Spacer (ISS, VertiFlex [11]. The approved surgical indication is for treating symptoms related to central canal-, foraminal stenosis, or Grade I degenerative spondylolisthesis in patients over 50 years [12].

Numerous other devices have been approved for clinical use in Latin America and Europe, some for additional indications. In general, osteoporosis, spondylolisthesis grade 2 and above, pars defects, ankylosis of the spinous processes, infection, severe neural element compression causing cauda equina, and excessive spinal deformity are contraindications to the procedure [12 - 15]. Some unpublished clinical trials have been started in the United States. Two Coflex® trials have been completed [16, 17], and another two Coflex® trials are scheduled for completion in June of 2022 and 2023, respectively (Table **1**) [18, 19]. The intradiscal and annular pressure have been shown to vary inversely between the extension and neutral position of the lumbar spine. Paolo *et al*. reported a 63% increase in posterior annular pressure in extension and 38% in the standing position with a simultaneous decrease of intranuclear pressure of 41% and 20%, respectively [20]. The authors demonstrated that most ISP increases spinal stability in extension, while a few also stabilize in flexion. However, none protected against instability in axial rotation or lateral stability [20].

Table 1. National Clinical Trial (NCT) on interspinous spacers.

NCT No.	Trial Name	Planned Enrollment	Completion Date
***NCT03041896**	Retrospective Evaluation of the Clinical and Radiographic Performance of Coflex® Interlaminer Technology *versus* Decompression With or Without Fusion	5000	Oct 2017
***NCT01316211**	Comparative Evaluation of Clinical Outcome in the Treatment of Degenerative Spinal Stenosis With Concomitant Low Back Pain by Decompression With and Without Additional Stabilization Using the CoflexTM Interlaminar Technology	245	Dec 2017
***NCT02555280**	A 2 and 5 Year Comparative Evaluation of Clinical Outcomes in the Treatment of Degenerative Spinal Stenosis With Concomitant Low Back Pain by Decompression With and Without Additional Stabilization Using the Coflex® Interlaminar Technology for FDA Real Conditions of Use Study (Post-Approval 'Real Conditions of Use' Study)	345	Jun 2022

CHAPTER 13

Awake Endoscopic Transforaminal Lumbar Interbody Fusion

Ibrahim Hussain[1,*] and **Michael Y. Wang**[1]

[1] *Department of Neurological Surgery, University of Miami, Miami, FL 33136, USA*

Abstract: The transforaminal interbody fusion (TLIF) is a time-tested procedure for treating various lumbar degenerative pathologies. This approach leverages an access route through Kambin's triangle that typically requires a partial or total facetectomy for access to the disc space and neural decompression. Since its first published description in the early 1980s, the procedure has undergone extensive refinements concomitant with technology and technique advancements. Traditional open TLIF is effective but associated with adverse perioperative effects due to the amount of muscle dissection necessary for exposure, including increased blood loss, hospital length of stay, and extended recovery times. The transition to more minimally invasive, paramedian approaches has sought to reduce the burden of these consequences. Spinal endoscopy has witnessed a resurgence over the past decade paralleled by advancements in higher resolution optical systems along with more robust and enduring endoscopic instrumentation. This development, combined with increased awareness of healthcare economic costs, problems with narcotic dependency surrounding open spine surgery, and admission restrictions to hospitals during pandemic times, has fueled a push for "ultra" minimally invasive variants of the traditional TLIF. Patients, payors, and hospitals alike expect shorter inpatient stays, earlier mobilization and discharge from the hospital, as well as narcotic independence faster than ever before. To this end, awake endoscopic TLIF has recently been described with efficacious results to comply with these broader factors. In this chapter, the authors explain their awake endoscopic TLIF step-by-step and demonstrate the clinical advantages and the noninferiority data to traditional MIS TLIF based on their clinical series's one-year outcomes data.

Keywords: Endoscopic interbody fusion, Posterior supplemental fixation, Transforaminal lumbar interbody fusion.

* **Corresponding author Ibrahim Hussain:** Department of Neurological Surgery, University of Miami, Miller School of Medicine, 1095 NW 14TH TER RM 2-06, Miami, FL 33136, USA; Tel: (908) 922-7635; E-mail: ixh212@med.miami.edu

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

INTRODUCTION

The transforaminal route for accessing the lumbar intervertebral disc was initially performed by Parviz Kambin in 1973, generating the anatomically-geometric structure referred to as "Kambin's triangle." Initial descriptions of his approach were for purposes of percutaneous discectomy, whereby a working cannula was inserted through the "safe" zone of Kambin's triangle for aspiration of nucleus pulposus [1, 2]. Almost a decade later, Jürgen Harms described a similar approach for interbody fusion, leveraging a total facetectomy and hemilaminectomy to provide a safe corridor for discectomy and graft insertion. Controversy in the literature persists regarding Kambin's triangle's actual borders and its application to spinal interbody grafting procedures, for which it was not described initially [3]. Modern-day descriptions have adopted a prism morphology to this space, with different angles of the approach based on the intended goal of surgery (Fig. **1**) [4].

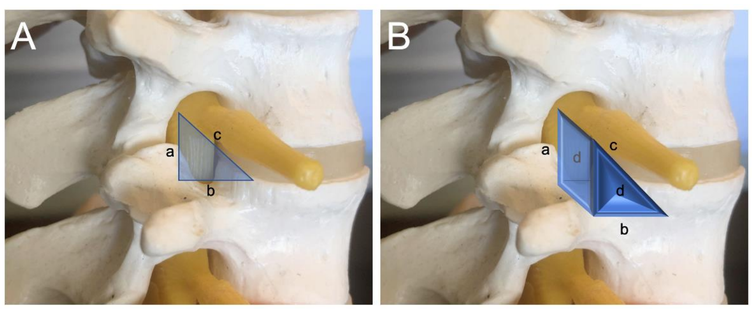

Fig. (1). Kambin's triangle *versus* Kambin's prism. **A)** In Kambin's original description, a two-dimensional triangle denoted the key anatomic landmarks. However, "a" was not assigned a specific structure, though implied the superior articulating process of the inferior vertebrae. "b" and "c" denoted the superior endplate of the inferior vertebra and the exiting nerve root (*i.e.* the "hypotenuse). **B)** In converting Kambin's triangle to a 3-dimensional prism, as described by Tumialán et al. [3], an additional structure can be included. This is "d" which denotes the thecal sac/traversing nerve root. The other structures (a-c) remain the same.

Since Harms' first description of the transforaminal interbody fusion (TLIF), the procedure has undergone revolutionary advancements yielding increasingly minimally-invasive alternatives. These advances have been generated concomitant with retractor technology developments (*i.e.*, tubular, specular), microscopy, and extended microsurgical instrumentation. These approaches allow a paramedian approach through the natural Wiltse plane to access the facet joint and, ultimately, the disc space [4]. Preservation of the posterior tension band while minimizing subperiosteal muscle dissection has demonstrated clear, durable advantages over the traditional midline approach. Numerous studies have shown that minimally-invasive surgery (MIS) TLIF results in lower blood loss, shorter hospital stay, faster recovery times, and less postoperative narcotic use while maintaining comparable clinical outcomes and fusion rates with conventional open TLIF [5 - 12]. Furthermore, comparative cost-effectiveness studies have demonstrated that MIS TLIF is superior to open TLIF with regards to hospital perspective costs (mean difference of $2,680 per surgery) and societal perspective costs attributed to lower absenteeism [12 - 21].

Endoscopic TLIF presents the newest iteration of an MIS-approach for TLIF. Reports of using an endoscope for spinal surgery were described as early as 1977 by Apuzzo et al. using the Hopkins rod lens system [22]. By the late 1990s, with growing interest and technology in MIS-approaches, endoscopic-assistance for performing TLIF in conjunction with tubular retractors was described by Foley and Fessler [23, 24]. These procedures typically used the endoscope as a visualization tool that could be substituted with the surgical microscope. Other technological barriers prevented wide-spread adoption at the time, in addition to a lack of billing codes and surgeon preferences. However, over the last two decades, enormous strides have been made in refining the endoscopic technology available in North America and its adaptation for performing a discectomy and interbody fusion. These include narrower rigid endoscopes, light-emitting diode (LED) illumination sources, ultra-high-definition optical displays, radiofrequency electrode probes for cauterization, disc preparation instruments, and expandable interbody grafts.

Endoscopic TLIF represents a facet of another increasingly recognized movement in MIS of "enhanced" or "fast-track" surgery [25 - 27]. These protocols employ multidisciplinary strategies to minimize complications and create a seamless patient experience that mitigates the burden of surgery and anesthesia. To this end, "awake" endoscopic TLIF was first described by the senior author in 2016 to reduce the extended stay, side-effects, and systemic limitations of general anesthesia, narcotic consumption, and overall healthcare costs with MIS TLIF [28 - 30]. In this chapter, we review the key technical steps of the "awake" endoscopic TLIF and up-to-date clinical outcomes.

ANESTHESIA & ENHANCED RECOVERY AFTER SURGERY (ERAS)

The ERAS pathway adopted for MIS endoscopic TLIF revolves around six core tenets. First, awake surgery is performed under monitored anesthesia care (MAC) rather than general endotracheal intubation. Typically, patients are pre-medicated with 1-2 mg of midazolam before coming to the operating room. After that, sedation maintenance is via a combination of propofol, ketamine, and dexmedetomidine infusions that are titrated until moderate (conscious) sedation is achieved [28]. At this stage, patients, remain asleep but are easily arousable. Supplemental oxygenations are provided by nasal cannular or face mask. Deep

CHAPTER 14

Endoscopic Transforaminal Lewlif™ Interbody Fusion with a Standalone Expandable Interbody Fusion Cage

Kai-Uwe Lewandrowski[1,2,3,*] and **Jorge Felipe Ramírez León**[4]

[1] *Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson, AZ, USA*

[2] *Departmemt of Orthopaedics, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA*

[3] *Visiting Professor Department of Neurosurgery in the Video-Endoscopic Postgraduate Program at the Universidade Federal do Estado do Rio de Janeiro — UNIRIO, Rio de Janeiro, Brazil*

[4] *Centro de Columna – Cirugía Mínima Invasiva. Bogotá, D.C., Colombia, Clínica Reina Sofía – Clínica Colsanitas. Bogotá, D.C., Colombia, Fundación Universitaria Sanitas. Bogotá, D.C., Colombia, USA*

Abstract: Endoscopic spinal fusion is on the horizon. Many surgeons have offered various endoscopically assisted decompression and fusion surgeries that consist of an interbody device and posterior supplemental screws. Stabilization of the spine *via* an anterior column fusion implant has excellent advantages of improving the fusion rate *via* bone graft containment. It can enhance spinal alignment and assist in direct and indirect decompression of neural elements *via* restoring normal lumbar curvature and neuroforaminal height. However, further use of posterior supplemental fixation has the disadvantage of adding to the operation's complexity in blood loss, time, equipment needs, and complications. Therefore, a simplified standalone anterior interbody fusion procedure to be carried out through the transforaminal approach *via* a small posterolateral skin incision was of interest to the authors of this chapter, who are introducing the complete endoscopic implantation of a threaded expandable cylindrical fusion cage. This fusion system was developed to mitigate subsidence and migration problems seen with non-threaded lumbar interbody fusion cages, many of which require posterior pedicle screw fixation. This chapter describes step-by-step transforaminal decompression fusion technique suitable for an outpatient ambulatory surgery center setting.

Keywords: Anterior column stabilization, Endoscopy, Interbody fusion.

[*] **Corresponding author Kai-Uwe Lewandrowski:** Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson, AZ, USA, Department of Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil and Department of Orthoapedic Surgery, Fundación Universitaria Sanitas, Bogotá, D.C., Colombia, USA; Tel: +1 520 204-1495; Fax: +1 623 218-1215; E-mail: business@tucsonspine.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

INTRODUCTION

Endoscopic surgery is increasingly favored by patients and surgeons alike for its simplicity in execution and low burden in postoperative recovery [1, 2]. Negligible blood loss, minimal incisional pain, fast mobilization, and a lower incidence of peri- and long-term postoperative problems are the primary motivators [3, 4]. However, the limits of the procedure seem to be at the decompression level. More complex clinical indications requiring the deployment of implants typically often cannot be completed through the small endoscopic access portals. Some authors have circumvented the problem with hybrid endoscopically assisted instrumented fusion procedures. Standalone endoscopic interbody fusion through the same small access portal without additional portals or enlarging the incisions is a novelty and became possible with the advent of expandable cages. The FDA approval of a cylindrical threaded expandable device designed for standalone interbody fusion without additional use of posterior supplemental fixation has provided both the technological and regulatory basis for a pure endoscopic interbody fusion procedure [5 - 7].

MIS lumbar interbody fusion cages stabilize the spine while restoring neuroforaminal height and fusion [8]. They may restore spinal curvature and aid indirect decompression of painful neural elements. Static interbody fusion cages have been around for more than two decades, and their clinical track record is well documented. Endplate decortication is ideally done by maintaining the integrity of the subchondral bone. Posterior pedicle screw fixation may improve stability and minimize the observed cage migration and subsidence problems [9 - 11] Pedicle screw fixation may add to operative time, increase blood loss, and lead to a higher complication rate [12 - 14], Propagation of adjacent segment disease is another concern [15]. A standalone endoscopic transforaminal decompression and fusion procedure would capitalize on time-proven benefits of minimal muscle dissection and access-related problems by employing advanced endoscopes and standard neurosurgical and motorized decompression instruments (Fig. **1**). With the advent of advanced foraminoplasty techniques, a combination of “outside-in” and “inside-out” techniques became feasible, allowing direct visualization of the epidural and intradiscal space during the same surgery.

Ideally, the implant has a large chamber for a bone graft. Moreover, openings allow the graft to fuse between the adjacent endplates, which can easily be monitored radiographically. In skilled hands, endplate preserving decortication techniques coupled with gentle advancement of a threaded device over a guidewire into the intervertebral disc space could be added without complicating the routine transforaminal endoscopic decompression surgery too much. Such an implant should be adjustable by a turning motion where clockwise rotation advances the threaded implant. The devices' counterclockwise turning retrieves it without losing the purchase. The expansion of the cage *in situ* distracts the adjacent endplates, thereby indirectly stabilizing the surgical motion segment *via* ligamentotaxis without the need for pedicle screws (Fig. **2**).

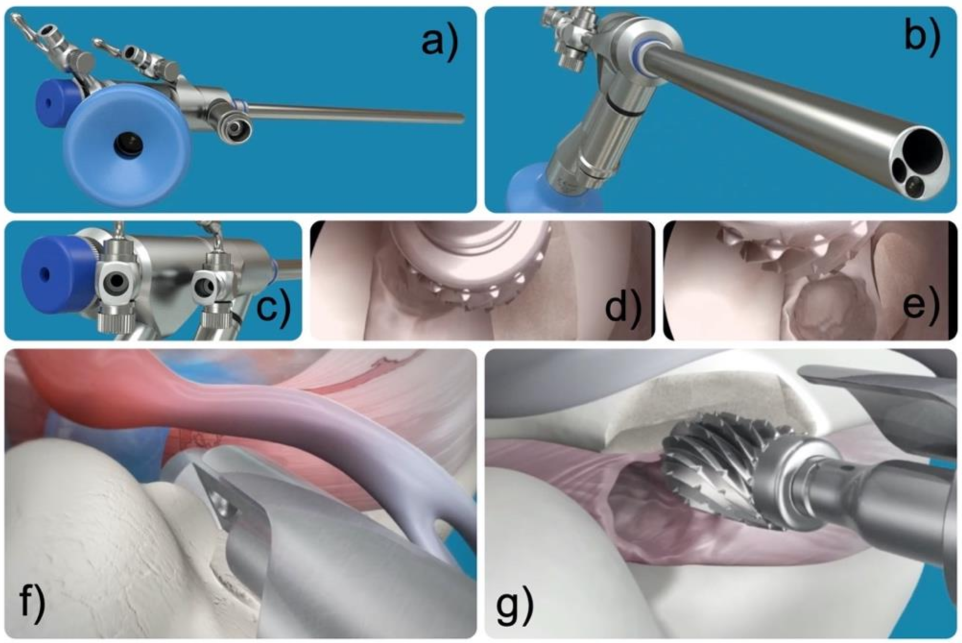

Fig. (1). Example of a modern foraminoscope **(a-b)** with a 4.1 mm inner working channel and integrated suction and irrigation channel **(c)** introduction of standard 4.0 mm diameter neurosurgical decompression tools becomes feasible. A motorized burr is employed to drill down osteophytes of the hypertrophic ring apophysis to prepare the cage's introitus **(d)**. The same burr may also be used to prepare entry into the disc space and prepare the endplates **(e)**. Kerrison rongers may be employed to perform the foraminoplasty by resecting parts of the superior **(f)** and inferior articular process **(g)**. The bladed tip of the beveled endoscopic working cannula is strategically positioned to retract the exiting nerve root (g).

PATIENT SELECTION CRITERIA

The authors began endoscopic spinal fusion in 2016 by building on the existing outpatient spinal surgery program. The main indication for this procedure is end-stage degenerative disc disease with associated grade I spondylolisthesis causing unrelenting radiculopathy and claudication symptoms unresponsive to conservative care supported by advanced imaging demonstrating foraminal or lateral recess stenosis. Patients with higher anterolisthesis or severe central stenosis defined as less than 100 mm^2 cross-sectional canal area [16], extreme facet hypertrophy, infection, and metastatic disease were excluded.

CHAPTER 15

Endoscopic Intravertebral Canal Decompression after Spinal Fracture

Xifeng Zhang[1,2,*], **Lei-Ming Zhang**[3] and **Jiang Letao**[4]

[1] *Department of Orthopedics, First Medical Center, PLA General Hospital, Beijing 100853, China*

[2] *Department of Orthopedics, Beijing Yuho Rehabilitation Hospital, Beijing 100853, China*

[3] *Department of Neurosurgery, Sixth Medical Center, PLA General Hospital, Beijing 100048, China*

[4] *Department of Orthopedics, Affiliated Hospital of Yangzhou University, Yangzhou 225001, China*

Abstract: Spinal endoscopy allows creating access to areas of the spine that are ordinarily difficult to reach, thereby reducing the collateral damage from extensive exposure to treat common degenerative or traumatic conditions of the spine. In this chapter, the authors present a case of endoscopic spinal canal decompression in a patient who sustained a burst fracture near the thoracolumbar junction. The endoscopic decompression technique was employed, which resulted in removing bone fragments, causing compression of the neural elements. The burst fracture was then stabilized with a percutaneous short pedicle screw construct. The patient did well with the hybridized endoscopic and minimally invasive decompression and stabilization technique. The authors are making a case for considering the endoscopic spinal surgery platform other than the traditionally accepted indications in the interest to diminish further blood loss, pain, and complication rates associated with spinal fracture surgeries.

Keywords: Endoscopic decompression, Hybridized endoscopic and minimally invasive technique, Percutaneous short pedicle screw construct, Thoracolumbar fracture.

INTRODUCTION

High energy trauma to the spine frequently causes fractures across the thoracolumbar junction [1]. Depending on the posterior-longitudinal ligament complex's integrity, the extent of canal compromise by posteriorly displaced bone fragments, and neurological deficits, surgery may be recommended to stabilize

* **Corresponding author Xifeng Zhang:** Department of Orthopedics, First Medical Center, PLA General Hospital, Beijing 100853, China and Department of Orthopedics, Beijing Yuho Rehabilitation Hospital, Beijing, 100853, China; Tel: (908) 922-7635; E-mail: xifengzhang301@outlook.com

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the spine and recover neurological function [2]. If the latter category of patients is left untreated, quality of life is typically severely impacted [2]. Burst fractures make up about 20% of all fractures of the thoracolumbar spine [3]. Several classification systems have been published delineating surgical indications *versus* non-operative treatment with braces [4]. Minimally invasive techniques have been tried to diminish blood loss further, reduce operation time while accomplishing canal decompression, and improving sagittal alignment [5 - 10]. Short pedicle screw constructs are center stage in the surgical stabilization of thoracolumbar fractures to avoid anterior column insufficiency with instability and kyphosis if left untreated [10 - 12]. However, posterior surgery alone is often insufficient to adequately decompress the spinal canal [13] - a notion of particular importance in patients with neurological deficits. Therefore, the authors of this chapter present a novel application of the endoscopic spinal surgery technique where they employ the endoscope to access the middle column to remove bone fragments from the spinal canal before internal fixation with the minimally invasive placement of percutaneous short pedicle screw constructs.

CASE DETAILS

We report on a 29-year-old male patient with a chief complaint of right-sided flank and back pain. The patient could not walk for one week after trauma and experienced severe pain after falling downstairs one week ago. After the initial bed rest, the pain was not resolved and instead became gradually severe and rendering the patient unable to walk. The symptoms worsened after sitting for a long time. Squatting and other daily activities also agravated his symptoms. The pain was so intense that the patient was unable to work and had difficulty with urination. He presented to our healthcare facility with symptoms consistent with conus medullaris syndrome. Before admission to our facility, the patient was treated with mannitol and steroid therapy in an outside hospital without much relief. On admission, physical examination showed tenderness over the T12, L1, L2 spinous process tenderness. There was preserved motor strength in the right lower extremity muscles assessed at 5/5. In the left lower limb, motor strength was severely diminished with no voluntary movement. The examination of this patient's incomplete spinal cord injury further revealed intact sensation pain, temperature, light touch, and deep sensation in both lower limbs was normal. The bilateral knee tendon and achilles tendon reflexes were also present. There were no upper motor neuron signs with absent clonus and without other pathological reflexes. The bilateral straight leg elevation test was negative, and he had a staggering gait. X-rays of the lumbar spine suggested L1 and L2 compression fractures (Fig. **1**). CT and MRI (not shown in this chapter) of the lumbar spine showed L1 and L2 compression fractures, with bone fragments occupying space in the spinal canal most consistent with a burst fracture of the L1 vertebral body

(Fig. **2**). The thoracolumbar injury classification and severity score (TLICS) [10] was 7 points, and therefore the indication for surgery was established. The patient decided to undergo surgical treatment. Percutaneous pedicle screw internal fixation was performed first to stabilize the spine and see whether the bone fragment would reduce as a result of the short pedicle screw construct [10]. A postoperative CT scan proved otherwise. Therefore, the authors performed a bilateral endoscopic transforaminal decompression of the spinal canal by removing several large bone fragments in piecemeal (Figs. **2** and **3**).

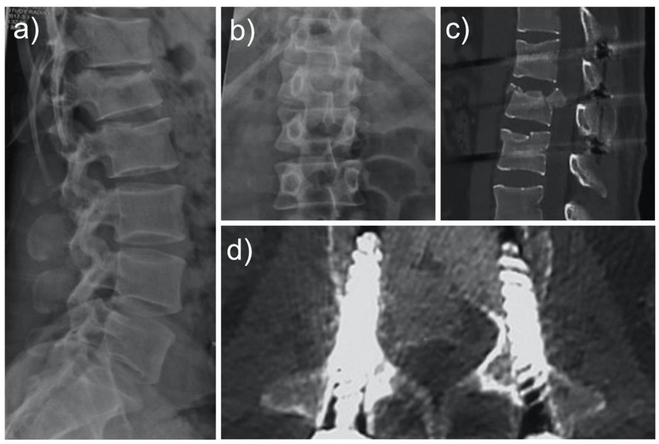

Fig. (1). Lateral (**a**) and anteroposterior (**b**) x-rays of the lumbar spine vertebrae showing L1 (burst) and L2 (compression) vertebral fracture are shown. The patient underwent percutaneous short pedicle screw fixation which did not reduce the posterior wall fragments. Postoperative CT scan of the lumbar spine showed large bone fragments to remain in the spinal canal typical of a burst fracture.

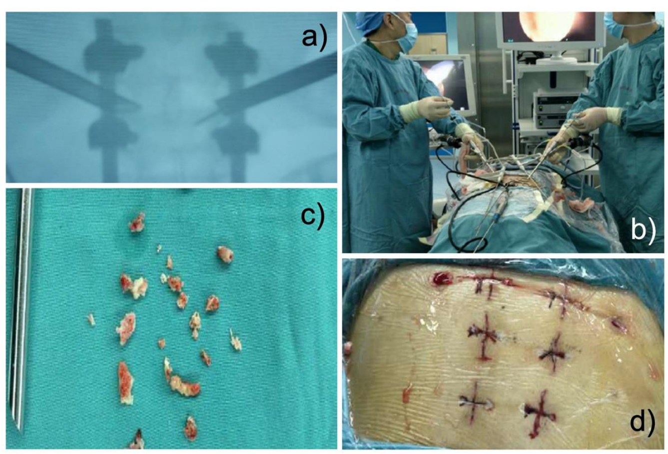

Fig. (2). The patient's canal compromise seen on postoperative CT scan (Fig. **1**) after initial percutaneous short pedicle screw construct prompted the surgeons to perform a bilateral (**a**) T12/L1 endoscopic transforaminal decompression (**b**) of the bone fragments anterior to dural sac. Several large bone fragments were removed endoscopically (**c**) through the bilateral paraspinal incisions (**d**).

CHAPTER 16

Treatment of Lumbar Tuberculosis with Spinal Endoscopy

Xifeng Zhang[1,2,*], **Du Jianwei**[3] and **Bu Rongqiang**[2]

[1] *Department of Orthopedics, First Medical Center, PLA General Hospital, Beijing 100853, China*

[2] *Department of Orthopedics, Beijing Yuho Rehabilitation Hospital, Beijing 100853, China*

[3] *Department of Orthopedics, Affiliated Hospital of Yangzhou University, Yangzhou 225001, China*

Abstract: The authors present a case of a 25-year old female patient who presented to their facility with a chief complaint of low back pain and discomfort for the previous two months. The symptoms gradually worsened. The patient denied any fever, night sweats, and other aches. Symptoms worsened when standing up. They were also aggravated by changing the body position. In particular, bending forward was restricted. There was no radiating pain in the lower extremities. An MRI of the lumbar spine revealed a lesion raising suspicions of tuberculosis of the spine, which was later confirmed with biopsy and cultures. The patient was placed on oral multi anti-tuberculosis antibiotic treatment but responded poorly to this treatment without much clinical improvement. Therefore, endoscopic access was chosen to debride and irrigate the paraspinal tuberculous abscess, which successfully treated the infection. The authors report the case details to illustrate that a combination of antibiotic treatment and endoscopic debridement may resolve the lumbar spine's complicated infection adequately. Minimally invasive endoscopic irrigation and lavage of paraspinal tuberculous abscesses can be considered an alternative to open surgery.

Keywords: Endoscopy, Irrigation & debridement, Lumbar spine, Tuberculosis.

INTRODUCTION

Tuberculosis (TB) of the spine is a disease of young adults and children. While TB should always be considered in the differential diagnosis of spinal infections in less developed countries, it is also on the rise in developed countries. Imaging studies typically show the destruction of the intervertebral disk space and the

* **Corresponding author Xifeng Zhang:** Department of Orthopedics, First Medical Center, PLA General Hospital, Beijing 100853, China and Department of Orthopedics, Beijing Yuho Rehabilitation Hospital, Beijing, 100853, China; Tel: (908) 922-7635; E-mail: xifengzhang301@outlook.com

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adjacent vertebral bodies, producing a vertical collapse of the spinal motion segment.

The kyphotic deformity may also develop mainly if the infection occurs at the thoracolumbar junction. However, the thoracic spine is the most commonly affected area of the spine. The infectious process is often walled off or may form a phlegmon, which may appear as a 'cold' abscess. Patients often complain of pain around the infected area. Spinal instability may result in neurological deficits if not treated on time. MRI is the imaging modality of choice as x-rays and CT-scans are not as sensitive and better show the vertebral bodies' infectious involvement on either side of the infected intervertebral disc and their destruction. Image-based needle biopsy of the infected area is key to making a definitive diagnosis *via* histopathological analysis and cultures. The index of clinical suspicion should be higher in immunocompromised patients, and in particular in those with HIV. Once the diagnosis is confirmed, anti-tuberculosis medical management remains the first-line treatment of choice. Surgery is considered only in those patients in whom medical treatment with antibiotics is ineffective. The prognosis is typically favorable if discovered and treated early in the disease process before spinal deformity, and neurological deficits ensue.

CLINICAL CASE

Physical examination of our 25-year old female patient showed normal spinal physical curvature, but some slight limitation of forward bending movement, mild low and mild lower back tenderness with negative percussive pain. The skin sensation, range of motion, and strength in both lower limbs were nearly symmetrical and normal. She had a positive straight leg raise test at minimal leg elevation. The laboratory testing on admission showed an elevated C-reactive protein of 18.24 mg/L and an erythrocyte sedimentation rate of 35 mm/h. Advanced imaging showed a destructive process at the L3/4 disc space with an associated paraspinal abscess (Fig. **1**). After admission, initial treatment consisted of standard oral anti-tuberculosis treatment. An endoscopic debridement of the infected area at the L3/4 level was performed after the non-operative care with antibiotics had failed (Fig. **2**). The endoscopic access to the infected intervertebral disc space was also used to place an irrigation drainage catheter into the infected area. At the same time, CT-guided needle aspiration of the abscess in the psoas major muscle was performed (Fig. **3**). This catheter was also used to inject anti-tuberculous medication into the psoas abscess for another ten days at the patient's bedside. After discharge from the hospital, the patient continued the daily irrigation of the abscess area with local antibiotic treatment in a similar way. At the final follow-up, the patient was noticed to have recovered from the spinal infection (Fig. **4**).

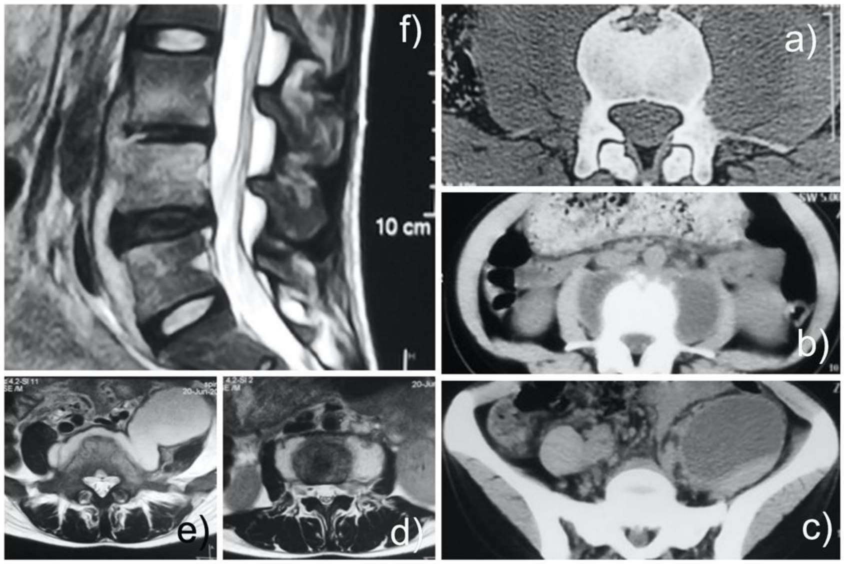

Fig. (1). The preoperative CT examination showed that the psoas major muscle was infected, and the vertebral bone was destroyed. Further investigation of preoperative MRI showed that the intervertebral space collapsed, the vertebral body destruction was relatively light, and the paravertebral infection abscess was huge.

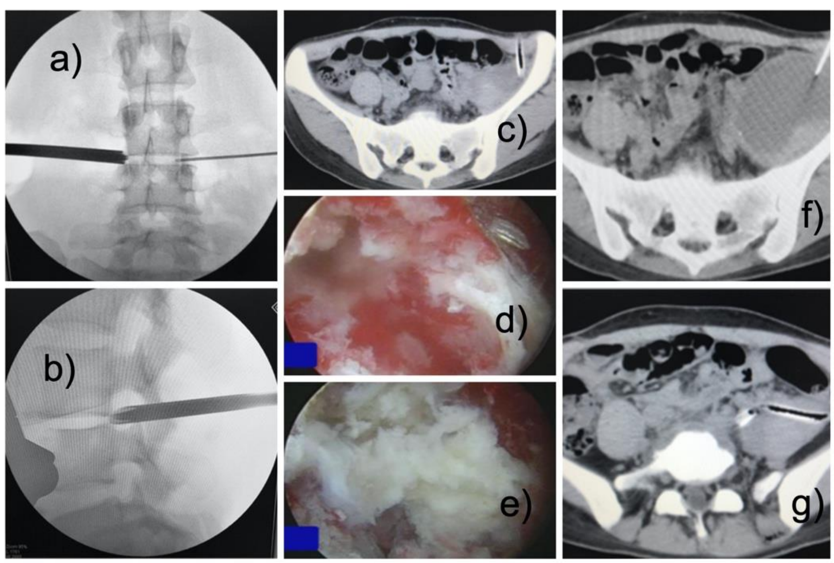

Fig. (2). Intraoperative puncture location **(a, b)**, the side with severe symptoms are cleared under endoscopy. A double-lumen perfusion irrigation tube is placed **(c)**, and an epidural tube is placed on the opposite side. Endoscopy shows the necrotic tissue in the intervertebral space and the situation after cleaning **(d, e)**. Selecting the largest part of the iliac fossa abscess, a CT-guided puncture to the abscess anteriorly was performed by placing an indwelling a double-cavity perfusion irrigation tube for continuous irrigation and drainage.

CHAPTER 17

Treatment of Degenerative Scoliosis with Percutaneous Spinal Endoscopy Assisted Interbody Fusion and Percutaneous Pedicle Screw Fixation

Xifeng Zhang[1,2,*], **Du Jianwei**[3], **Lei-Ming Zhang**[4] and **Wang Yu**[3]

[1] *Department of Orthopedics, First Medical Center, PLA General Hospital, Beijing 100853, China*

[2] *Department of Orthopedics, Beijing Yuho Rehabilitation Hospital, Beijing 100853, China*

[3] *Department of orthopedics, Affiliated Hospital of Yangzhou University, Yangzhou 225001, China*

[4] *Department of orthopedics, Sixth Medical Center, PLA General Hospital, Beijing 100048, China*

Abstract: Deformity correction is an integral part of spinal surgery. For patients with painful coronal and sagittal plane deformity, correction to restore lumbar lordosis and scoliosis is the surgical treatment goal. Traditional open spinal surgery techniques are associated with wound problems, long-recovery times, high blood loss, and many other disadvantages compared to their more modern minimally invasive counterparts. While the minimally invasive percutaneous placement of pedicle-screw-rod constructs has been tried, anterior column release and fusion techniques to facilitate deformity correction often require excessive surgical exposures to gain access to the anterior column. This chapter presents a percutaneous transforaminal endoscopic interbody decompression and fusion technique to release the anterior column and facilitate deformity correction with the posterior column pedicle screw constructs. When combined with percutaneous minimally invasive screw placement, the patient's overall burden by the long-segment spinal fusion procedure can be significantly lowered by simplifying the entire procedure and carrying it out through small percutaneous incisions. An illustrative case is presented to demonstrate the utility of endoscopically assisted interbody fusion in scoliosis patients.

Keywords: Coronal plane deformity correction, Endoscopic surgery, Interbody fusion, Long-segment, Percutaneous pedicle screws, Scoliosis.

* **Corresponding author Xifeng Zhang:** Department of Orthopedics, First Medical Center, PLA General Hospital, Beijing 100853, China and Department of Orthopedics, Beijing Yuho Rehabilitation Hospital, Beijing, 100853, China; Tel: (908) 922-7635; E-mail: xifengzhang301@outlook.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

INTRODUCTION

Nowadays, surgical correction of adult degenerative scoliosis in patients with unrelenting symptoms who have been unresponsive to conservative care is commonplace [1 - 4]. Typically, the condition is slowly progressive, and many patients put up with the symptoms for many years before seeking medical attention and even before considering surgery [2]. Pain generators reside within the asymmetrically degenerated and vertically collapsed intervertebral disc space, the arthritic facet joints, which often show significant hypertrophy. The instability-induced degenerative process may lead to disc bulges and thickening of the ligamentum flavum [4]. Consequently, pain and weakness may develop due to these structural changes producing spinal stenosis in the central canal and foraminal nerve root entrapment. The latter may add a radicular pain component to the mechanical deformity-driven pain component. Reduced walking endurance and increasing difficulty with activities of daily living is the consequence. By nature of the coupled motion within the thoracolumbar spine dictated by the facet joint anatomy, the coronal plane deformity is associated with rotatory deformity, and lateral listhesis, which is least well tolerated by patients and often prompts surgery. The asymmetric multilevel vertical collapse of the intervertebral disc spaces may lead to progressive loss of lumbar lordosis potentiating the coronal and sagittal plane deformity and disruption of spinopelvic proportions [5]. Osteoporotic vertebral compression fractures may aggravate this situation.

Many patients with adult degenerative scoliosis are coming up for surgery at older ages [6, 7]. At that point, many of them suffer from medical comorbidities that may place them at a higher risk for surgery [8, 9]. Therefore, surgeons have been looking for ways on how to simplify surgical treatment for such patients. For example, a smaller subset of patients with symptomatic degenerative scoliosis who predominantly present with radicular pain stemming from single-level unilateral nerve root compression may be a candidate for a minimally invasive foraminal decompression to lower the perioperative risks with open multilevel surgeries [10]. In this chapter, the authors are presenting their way of simplifying the surgical treatment of patients who have symptomatic degenerative scoliosis by combining the endoscopically assisted interbody fusion procedure with a threaded and expandable interbody fusion cage with percutaneously placed pedicle screws connected to a long-rod construct to decompress neural elements while correcting the deformity. While the surgical indications for degenerative thoracolumbar scoliosis are subject to constant debate, the authors by no means intended to weigh in on that discussion. Instead, they merely intended to illustrate how to employ the endoscope during such complex spinal surgery so that the operation can be simplified to the patient's advantage.

CASE DETAILS

The patient of our illustrative case is a 56-year-old female with a chief complaint of low back pain for the last 20 years. Additionally, she complained of left lower extremity radicular pain that has been going on for the previous seven years but recently experienced worsening pain over the last 20 days. There was normal 5/5 motor strength with normal sensation to light touch, pinprick, and temperature on physical examination. Proprioception and lower extremity reflexes were also normal, and pathological upper motor neuron signs were absent. Advanced imaging studies, including an MRI scan of the thoracolumbar spine, revealed progressive degenerative changes with associated spinal stenosis at the L1/2, L2/3, L3/4, and L4/5 levels. Further radiographic and clinical evaluation at the First Affiliated Hospital of Harbin Medical University determined that the patient suffered from radicular and mechanical pain in the lumbar spine based on a 32° degenerative lumbar scoliosis with multilevel vertical collapse, a small rotatory component, and loss of lumbar lordosis with flattening of the thoracolumbar spine (Fig. **1**). Surgery with multilevel foraminal decompression with interbody fusion cages and a long-rod construct was suggested to the patient since she had failed multiple rounds of non-operative care measures and could no longer function with her daily activities. However, the patient was still deemed well balanced, so an osteotomy was not advised.

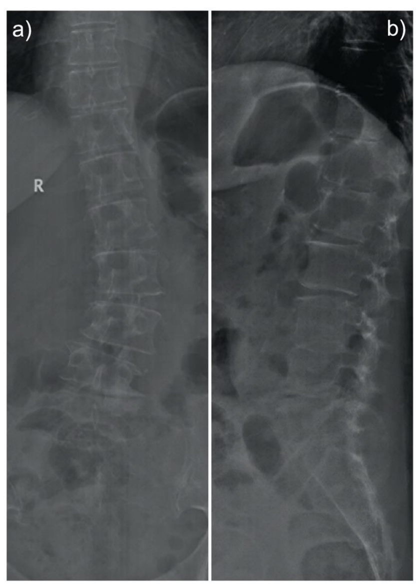

Fig. (1). Shown are anteroposterior **(a)** and lateral **(b)** views of the lumbar spine showing scoliosis with a measured Cobb angle of 32°. The patient's radiographic sagittal balance examination shows loss of normal lordosis with some lumbar spine flattening.

CHAPTER 18

Treatment of Thoracic Meningioma with Spinal Canal Decompression under Spinal Endoscopy

Xifeng Zhang[1,2,*], **Lei-Ming Zhang**[3] and **Yang Liu**[4]

[1] *Department of Orthopedics, First Medical Center, PLA General Hospital, Beijing 100853, China*

[2] *Department of Orthopedics, Beijing Yuho Rehabilitation Hospital, Beijing 100853, China*

[3] *Department of Orthopedics, Sixth Medical Center, PLA General Hospital, Beijing 100048, China*

[4] *Department of Orthopedics, Affiliated Hospital of Yangzhou University, Yangzhou 225001, China*

Abstract: Extramedullary benign tumors of the spine may cause spinal cord compression. Patients may present with motor weakness and sensory loss in the extremities causing gait abnormalities. Surgical treatment is indicated when symptoms are no longer manageable. In this chapter, the authors present an 87-year-old female's case as an illustrative example of how the spinal endoscopy platform can be safely and effectively deployed in the treatment of such lesions. The example patient suffered from spinal cord compression from a large meningioma at the T7 level. The tumor was successfully removed *via* an endoscopic working cannula. The patient's symptoms improved, and a nine-month follow-up MRI scan showed adequate and maintained spinal cord decompression. This case example demonstrates that spinal endoscopy may be applied to an increasing number of surgical indications beyond the scope of degenerative disease. Further clinical investigation will need to show this technology's limits when treating benign tumors of the spine.

Keywords: Endoscopic decompression, Extramedullary benign tumors, Spinal cord compression.

INTRODUCTION

Meningiomas are mostly common intramedullary spinal tumors. Extramedullary spinal meningiomas have been reported to have four times higher recurrence rates [1] and to be locally more aggressive [2]. While extramedullary spinal meningiomas are rare, their intramedullary counterpart occurs in the thoracic

* **Corresponding author Xifeng Zhang:** Department of Orthopedics, First Medical Center, PLA General Hospital, Beijing 100853, China and Department of Orthopedics, Beijing Yuho Rehabilitation Hospital, Beijing, 100853, China; Tel: (908) 922-7635; E-mail: xifengzhang301@outlook.com

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

spine 80% of the time in individuals between the ages 50 to 60 and with women four times more often than men [3].

In comparison, extramedullary spinal meningiomas make up 3.3%–7.8% of all spinal meningiomas [4]. The age distribution of patients diagnosed with an extramedullary meningioma is much wider than with intramedullary meningiomas and ranges between 14 – 75 years with nearly half of the affected patients being younger than 30 years and the majority being women [5]. Extramedullary meningiomas occur mostly in the thoracic spine and cervical spine [6, 7]. In this chapter, the authors demonstrate their minimally invasive management style of extramedullary benign spinal tumors employing spinal endoscopy without attempting an in-depth discussion of their differential diagnosis, clinical outcomes, and management.

CASE DETAILS

The patient is an 87-year-old female with a chief complaint of unsteady gait for the last one and a half years, causing increasing numbness and clumsiness in both lower limbs for six months. Symptoms started without any provoking event. Proprioception was altered as the patient stated she felt that she was walking on cotton. There were no spontaneous twitches. There was no incontinence. The diagnosis and treatment were delayed. As symptoms worsened over the previous year before presentation to our clinic, the patient noted increasing coldness and swelling of both lower extremities and decreased sensation in the left lower extremity. The admission to our facility was prompted by the above symptoms gradually worsening. Our team's initial physical revealed staggering gait, loss of sensation below the groin on both sides, but a free normal movement with 5/5 motor strength and normal muscle tone of the bilateral lower extremities. Of the advanced imaging studies, the thoracic MRI scan showed an extramedullary round lesion at the T7 level well visualized on the T1- and short-echo T2-weighted image. The lesion measured approximately 8 x 11 x 15 mm with a clearly delineated margin, causing compression of the spinal cord (Fig. **1**).

The patient became increasingly myelopathic with unmanageable symptoms leading up to the admission to our healthcare facility. Therefore, surgical decompression of the thoracic meningioma was indicated. The surgical team opted for an endoscopic decompression to minimize wound trauma and to simplify this patient's care. Therefore, a minimally invasive spinal endoscopic posterior laminectomy was contemplated to remove the tumor. The patient was positioned in a prone position on the spinal frame, and the surgery was performed under local anesthesia by infiltrating the surgical area with 1% lidocaine. Intraoperative fluoroscopy in multiple projections was used to accurately position the endoscopic working cannula after serial dilation over a guidewire, which had been placed over a spinal needle.

Fig. (1). An extramedullary round lesion at the T7 level well visualized on the T1-**(a)** and short-echo T2-weighted **(b)** image is shown. The lesion measured approximately 8 x 11 x 15 mm with a clearly delineated margin, causing the spinal cord's compression.

The surgical team was aware of the need for minimal manipulation of the spinal cord and careful drilling with the endoscopic power bur to remove the thoracic lamina at the T7 level to gain access to the spinal canal. Once access to the spinal canal was achieved, the meningioma was carefully dissected off the spinal cord without much difficulty. The stalk was identified and transected, allowing extirpation of the lesion in toto. Postoperatively, the patient was treated with supportive rehabilitation measures and improved significantly with near-complete gait some nine months postoperatively. No obvious postoperative complications were encountered. MRI imaging performed at that time showed adequate spinal cord decompression at the T7 level (Fig. **2**).

DISCUSSION

Meningiomas mostly originate from spinal cord arachnoid cells. The tumor grows slowly and often compresses the spinal cord, leading to spinal cord edema, nerve fiber degeneration, and ischemia, and eventually spinal cord damage. The clinical diagnosis is typically made on the MRI scan, determining the relationship between meningioma and surrounding tissues. The latter or the spinal cord are rarely invaded, making surgical extirpation of the lesion the treatment of choice. Meningiomas grow slowly, and clinically symptomatic recurrences are rare. The tumor is well visualized on routine T1- and T2 weighted MRI scans by demonstrating equal signal or slightly low signal intensity and uniform

CHAPTER 19

Cervical Endoscopic Unilateral Laminotomy for Bilateral Decompression (CE-ULBD) – A Technical Perspective

Vincent Hagel[1,*] and **Kai-Uwe Lewandrowski**[2,3,4]

[1] *Asklepios Hospital Lindau, Spine Center, Lindau, Germany*

[2] *Center for Advanced Spine Care of Southern Arizona and Surgical Institute of Tucson, Tucson AZ, USA*

[3] *Associate Professor of Orthopaedic Surgery, Universidad Colsanitas, Bogota, Colombia, USA*

[4] *Visiting Professor, Department Orthopaedic Surgery, UNIRIO, Rio de Janeiro, Brazil*

Abstract: Cervical endoscopic unilateral laminotomy for bilateral decompression (CE-ULBD) is an applicable surgical method in cases of central canal stenosis, usually associated with myelopathy. Other authors have shown the feasibility, safety, and efficacy of this method. They could also demonstrate more favorable perioperative benchmark data of this procedure than anterior cervical discectomy and fusion (ACDF) in terms of duration of surgery, blood loss, and hospital stay. In this chapter, the authors focus on the technological advances making this surgery possible. Moreover, the authors review the relevant surgical anatomy to enable the aspiring endoscopic spine surgeon to safely and successfully perform the CE-ULBD procedure. Experience in advanced endoscopic surgery in other areas of the spine is recommended before imparting on the posterior endoscopic decompression of the stenotic central cervical spinal canal. The authors have implemented CE-ULBD in formalized and well-structured Endoscopic Spine Academy (Espinea®) training programs, intending to provide high educational standards to achieve favorable outcomes with the CE-ULBD procedure reproducibly.

Keywords: Cervical myelopathy, Cervical spinal canal stenosis, CE-ULBD, Laminotomy, Posterior cervical endoscopic decompression, Spinal cord compression.

* **Corresponding author Vincent Hagel:** Asklepios Hospital Lindau, Spine Center, Lindau, Germany; E-mail: vhagel@yahoo.de

Kai-Uwe Lewandrowski, Jorge Felipe Ramírez León, Anthony Yeung, Gun Choi, Stefan Hellinger and Álvaro Dowling (Eds.)

INTRODUCTION

Degenerative cervical central canal stenosis is the most common cause of cervical myelopathy [1 - 11]. The progressive narrowing of the cervical spinal canal causes mechanical compression of the spinal cord. Hypoperfusion and segmental instability may add to the onset of symptoms, possibly causing rapid clinical deterioration [12]. Symptoms vary from fine motor deficits of the upper extremities, ataxia, hypesthesia of the lower extremities to bladder/bowel dysfunction [13, 14]. Several anatomical structures can cause central canal stenosis of the cervical spine. Typical reasons in the anterior spinal column are spondylotic changes leading to disc bulging [15] or ossification of the posterior longitudinal ligament [16]. In the posterior spinal column, medullary compression is mainly due to hypertrophic ligamentum flavum [5, 17, 18]. Compared to the lumbar spine, hypertrophy of the facet joint rarely contributes to stenosis [15]. The current literature remains unclear when surgically treating patients with a mild stenosis/myelopathy [11] and normal electrophysiological findings is indicated [15]. While these are individual decisions, in moderate and severe stenosis/myelopathy, there is no doubt about early surgical decompression being the treatment of choice [13, 19].

SURGICAL OPTIONS

Surgical options include a ventral or dorsal approach. While most surgeons are more familiar with and prefer a ventral approach [13, 19 - 21], there are circumstances where the posterior approach may be preferable [2, 21]. Several factors may dictate the approach of choice to the cervical spine. For example, the site of the maximum compression, the degree of stability, and the sagittal profile influences this decision-making [2]. A hypertrophic yellow ligament with or without associated kyphosis may dictate the posterior approach [15, 17]. In microsurgical techniques, posterior approaches to the cervical spine usually create significant destruction of the paravertebral musculature, generating prolonged neck pain, adding to kyphosis, or possibly evoking instability [22]. Endoscopic posterior approaches, on the other hand, seem to minimize these disadvantages [23 - 29]. However, few studies have compared the endoscopic approach to conventional open techniques to the cervical spine [30, 31]. Yet comparative studies from other spine areas suggest a reduced risk of postoperative kyphosis, instability, and infection [32 - 34]. The authors' preferred technique is the cervical endoscopic unilateral laminotomy for bilateral decompression (CE-ULBD) [30, 35].

PROCEDURAL STEPS

Choice of Endoscope

Different sized endoscopes can be used to perform a CE-ULBD. The most common ones have an overall diameter of 7.3 mm, or 10 mm (Fig. **1**). The smaller-sized endoscope provides more flexibility, thereby facilitating contralateral decompression. It also causes slightly less soft tissue trauma. On the other hand, a larger-diameter endoscope allows for introducing larger instruments and, consequently, more aggressive and perhaps faster decompression (Fig. **2**). Also, its working sleeve remains outside the canal throughout the procedure, leading to less risk of accidentally compressing the spinal cord.

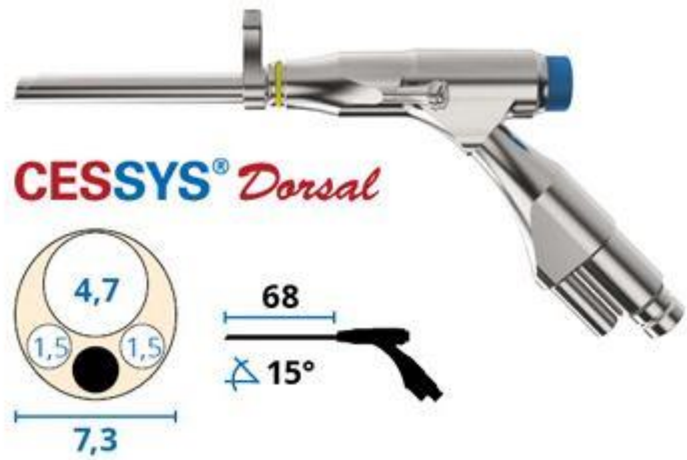

Fig. (1). Cervical endoscope CESSYS® Dorsal of Joimax™ with a 4.7 mm inner working channel.

Fig. (2). The iLESSYS® Delta endoscope by Joimax™ with a 6.0 mm inner working channel is also suitable for the posterior cervical decompression.

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KAI-UWE LEWANDROWSKI

Dr. Lewandrowski has dedicated his career to developing and implementing formalized endoscopic spinal surgery protocols by applying his NIH- and SBIR-funded academic research background to clinical investigation with sophisticated statistical analysis. His acumen has enabled him to build an entrepreneurial outpatient spinal surgery program that provides quality medical care to many patients.

JORGE FELIPE RAMÍREZ LEÓN

Dr. Ramirez is the number one key opinion leader in the Spanish-speaking world - an entrepreneur innovator spine surgeon who has advanced spinal endoscopy as a physician, business owner, and current or past president of the leading Latinamerican spine societies.

ANTHONY YEUNG

Dr. Yeung is the world's most renowned spinal endoscopist who was there at the beginning when it all started some 35 years ago. He was one of the first in the United States to begin his own vertically integrated ambulatory surgery center focused on endoscopic outpatient spine care.

Endoscopic surgery of the spine is a technology-driven subspeciality. Mastering this high-tech equipment in managing painful conditions of the spine depends on the surgeon's understanding of the symptomatic pathoanatomy and skill level. High-definition direct video visualization and simultaneous endoscopic treatment of the pain generator are essential to consistently achieving favorable clinical outcomes. In the third volume of Contemporary Endoscopic Spine Surgery: Advanced Technologies, the editors describe the industrial science behind modern endoscopic instrumentation and explain the development of more accurate preoperative predictors of a favorable outcome with endoscopic intervention utilizing correlative analysis of MRI with endoscopically visualized pathology as well as artificial intelligence applications. This multi-authored medical monograph segues into illustrating advanced reconstructive endoscopic spine procedures requiring a high level of exceptional surgeon skills.

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