2022 UCSF Pediatric and Adult Spine Surgery Course

Presented by the Department of Orthopaedic Surgery
University of California, San Francisco

COURSE CHAIRS
Lionel N. Metz, MD
Kyle A. Mitsunaga, MD
Lee A. Tan, MD

HONORED SPEAKERS
Serena S. Hu, MD
Vincent C. Traynelis, MD
Alexander R. Vaccaro, MD, PhD, MBA

Wednesday - Saturday
July 13-16, 2022
Royal Hawaiian Hotel • Honolulu, Hawaii
Department of Orthopaedic and Neurological Surgery of the University of California, San Francisco presents

UCSF
Pediatric and Adult Spine Surgery Course

July 13-16, 2022
The Royal Hawaiian
Honolulu, HI

Course Chairs
Lionel Metz, MD
Lee Tan, MD
Kyle Mitsunaga, MD

University of California, San Francisco
Acknowledgement of Commercial Support

This CME activity was supported in part by in-kind grants from the following:

ATEC Spine
DePuy Synthes Spine
Medtronic
NuVasive
SI-BONE
Stryker
Exhibitors

4Web
Accelus
Amplify Surgical
ATEC Spine
Bioventus
Carlsmed
Cerapedics
DePuy Synthes Spine
Evolution Spine
Globus Medical
Kurosbio
Medacta
Medtronic
Mirus Medical
NuVasive
Spine Art
Stryker
The Queen’s Health System
UCSF: Pediatric and Adult Spine Surgery Course

The UCSF Pediatric and Adult Spine Surgery Course is a three-and-a-half day event emphasizing pioneering trends in pediatric and adult spinal surgery. This course is designed to be interactive with didactic lectures given by leaders in the spine community as well as a hands-on bioskills lab. Participants will review and practice surgical principles and techniques in the treatment of complex spinal disorders. Expert lecturers will describe the state-of-the-art treatment for a variety of Pediatric and Adult Spinal Disorders. Interactive case presentations will allow learners to apply knowledge to improve decision making for complex spine pathology.

Residents, fellows, and surgeons wanting to broaden their hands-on experience will have the opportunity to improve skills in evaluating, case planning, and performing techniques to address various pediatric and adult spine pathologies.

Educational Objectives
Upon completion of this program, attendees will be able to:

- Understand the indications, applications and surgical techniques for posterior column osteotomies, interbody fusion techniques, transpedicular osteotomy, and corpectomy techniques for spinal reconstruction.
- Interpret and apply current, best available evidence to assess sagittal alignment in the adult and pediatric deformity patient.
- Understand the options for interbody fixation and fusion, and techniques to achieve optimal arthrodesis.
- Demonstrate understanding of the appropriate application of “minimally invasive” surgical techniques.
- Evaluate and treat pain related to spinal disorders in a cost-effective and reliable manner based on recently published guidelines.
- Understand appropriate indications for surgery to treat various spinal pathology including degenerative disorders, spinal deformities, and tumors and deploy suitable surgical approaches to achieve goals of care.
- Evaluate and treat lumbar degenerative disease and deformity in a cost-effective manner based on an evidence based approach and understand how to mitigate morbidity and risk.
- Avoid perioperative complications by identifying risk factors that may predispose individuals to perioperative morbidity. Determine modifiable risk factors and strategies for effective optimization.
- Diagnose spinal instability related to spinal tumors and formulate surgical treatment plans to address neurological deficits, pain, and instability in spine oncology patients based on published guidelines.
- Compare techniques and outcomes of procedures involving the cervical, thoracic, lumbar spine disorders and spinal tumors.
- Gain experience in the anatomical and technical subtleties of complex cervical, thoracic, and lumbar surgical procedures in a hands-on proctored cadaver lab experience with state of the art instruments and technology available to the participant.
- Understand the subtleties of patient selection for various procedures to optimize efficacy and safety in access to and instrumentation of all areas of the spine in both adult and pediatric patients.
- Correlate radiographic findings to surgical anatomy as they pertain to the approach and techniques for minimizing complications.
- Refine and optimize preoperative and operative treatment planning for adult and pediatric patients.
The University of California, San Francisco School of Medicine (UCSF) is accredited by the Accreditation Council for Continuing Medical Education to provide continuing medical education for physicians.

**Physicians**
UCSF designates this live activity for a maximum of 20.50 *AMA PRA Category 1 Credits™*. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

This CME activity meets the requirements under California Assembly Bill 1195, Continuing Education and Cultural and Linguistic Competency.

**Nurses**
For the purpose of recertification, the American Nurses Credentialing Center accepts *AMA PRA Category 1 Credit™* issued by organizations accredited by the ACCME.

**Physician Assistants**
AAPA accepts category 1 credit from AOACCME, Prescribed credit from AAFP, and *AMA PRA Category 1 Credit™* from organizations accredited by the ACCME.

**Pharmacists**
The California Board of Pharmacy accepts as continuing professional education those courses that meet the standard of relevance to pharmacy practice and have been approved for *AMA PRA Category 1 Credit™*. 
General Information

Attendance Verification/ Sign-In Sheet
Please remember to sign-in on the sign-in sheet when you check in at the UCSF Registration Desk on your first day. You only need to sign-in once for the course, when you first check in.

Speaker Survey – Electronic
On Wednesday, July 13th you will receive an email from Sari.Will@ucsf.edu through the Qualtrics system with a personalized link to access the Speaker Survey. Please make sure that you add this email to your safe senders list. If you did not receive the link, please see the UCSF Registration Desk. The Speaker Survey is to be completed in real time during the course and is separate from the Evaluation/CME Certificate.

Course Evaluation / CME Certificates
After the morning coffee break on Saturday, July 16th, you will receive another Sari.Will@ucsf.edu through the Qualtrics system to complete your online Course Evaluation/ CME Certificate. The Qualtrics system will send you reminders to complete your Course Evaluation/ CME Certificate until you complete it.

Upon completing the Course Evaluation/ CME Certificate, your CME certificate will be automatically generated to print and/or email yourself a copy. For smartphone users, you may want to take a photo of your certificate as some settings prevent you from emailing the certificate.

The link will be available for 30 days after the last day of the course. However, after that date the link will expire and you will no longer be able to claim your credits online. You must then contact the Office of CME at registration@ocme.ucsf.edu to receive your certificate and a $15 administrative fee may be applied.

Security
We urge caution with regard to your personal belongings and syllabus books. We are unable to replace these in the event of loss. Please do not leave any personal belongings unattended in the meeting room during lunch or breaks or overnight.

Exhibits
Industry exhibits will be available in Regency Ballroom III during continental breakfast and breaks.

Phone Messages
Any messages during the conference can be left by calling (808) 923-7311 and asking to deliver a message to the UCSF Spine Course Registration Desk.

Final Presentations
A link to PDF versions of the final presentations will be sent via e-mail approximately 2-3 weeks post course. Only presentations that have been authorized for inclusion by the presenter will be included.

Luau Reception
We are pleased to host the Luau Reception on Wednesday, July 13th starting at 6:15pm at the Azure Restaurant.

Lunch
On Thursday, July 14th and Friday, July 15th a lunch will be provided for all registered attendees. Please note that it is only for registered attendees and you will need your name badge to enter.
Federal and State Law
Regarding Linguistic Access and Services for Limited English Proficient Persons

I. Purpose.
This document is intended to satisfy the requirements set forth in California Business and Professions code 2190.1. California law requires physicians to obtain training in cultural and linguistic competency as part of their continuing medical education programs. This document and the attachments are intended to provide physicians with an overview of federal and state laws regarding linguistic access and services for limited English proficient (“LEP”) persons. Other federal and state laws not reviewed below also may govern the manner in which physicians and healthcare providers render services for disabled, hearing impaired or other protected categories.

The Federal Civil Rights Act of 1964, as amended, and HHS regulations require recipients of federal financial assistance (“Recipients”) to take reasonable steps to ensure that LEP persons have meaningful access to federally funded programs and services. Failure to provide LEP individuals with access to federally funded programs and services may constitute national origin discrimination, which may be remedied by federal agency enforcement action. Recipients may include physicians, hospitals, universities and academic medical centers who receive grants, training, equipment, surplus property and other assistance from the federal government.

HHS recently issued revised guidance documents for Recipients to ensure that they understand their obligations to provide language assistance services to LEP persons. A copy of HHS’s summary document entitled “Guidance for Federal Financial Assistance Recipients Regarding Title VI and the Prohibition Against National Origin Discrimination Affecting Limited English Proficient Persons – Summary” is available at HHS’s website at: http://www.hhs.gov/ocr/lep/.

As noted above, Recipients generally must provide meaningful access to their programs and services for LEP persons. The rule, however, is a flexible one and HHS recognizes that “reasonable steps” may differ depending on the Recipient’s size and scope of services. HHS advised that Recipients, in designing an LEP program, should conduct an individualized assessment balancing four factors, including: (i) the number or proportion of LEP persons eligible to be served or likely to be encountered by the Recipient; (ii) the frequency with which LEP individuals come into contact with the Recipient’s program; (iii) the nature and importance of the program, activity or service provided by the Recipient to its beneficiaries; and (iv) the resources available to the Recipient and the costs of interpreting and translation services.

Based on the Recipient’s analysis, the Recipient should then design an LEP plan based on five recommended steps, including: (i) identifying LEP individuals who may need assistance; (ii) identifying language assistance measures; (iii) training staff; (iv) providing notice to LEP persons; and (v) monitoring and updating the LEP plan.

A Recipient’s LEP plan likely will include translating vital documents and providing either on-site interpreters or telephone interpreter services, or using shared interpreting services with other Recipients. Recipients may take other reasonable steps depending on the emergent or non-emergent needs of the LEP individual, such as hiring bilingual staff who are competent in the skills required for medical translation, hiring staff interpreters, or contracting with outside public or private agencies that provide interpreter services. HHS’s guidance provides detailed examples of the mix of services that a Recipient should consider and implement. HHS’s guidance also establishes a “safe harbor” that Recipients may elect to follow when determining whether vital documents must be translated into other languages. Compliance with the safe harbor will be strong evidence that the Recipient has satisfied its written translation obligations.

In addition to reviewing HHS guidance documents, Recipients may contact HHS’s Office for Civil Rights for technical assistance in establishing a reasonable LEP plan.

The California legislature enacted the California’s Dymally-Alatorre Bilingual Services Act (Govt. Code 7290 et seq.) in order to ensure that California residents would appropriately receive services from public agencies regardless of the person’s English language skills. California Government Code section 7291 recites this legislative intent as follows:

“The Legislature hereby finds and declares that the effective maintenance and development of a free and democratic society depends on the right and ability of its citizens and residents to communicate with their government and the right and ability of the government to communicate with them.

The Legislature further finds and declares that substantial numbers of persons who live, work and pay taxes in this state are unable, either because they do not speak or write English at all, or because their primary language is other than English, effectively to communicate with their government. The Legislature further finds and declares that state and local agency employees frequently are unable to communicate with persons requiring their services because of this language barrier. As a consequence, substantial numbers of persons presently are being denied rights and benefits to which they would otherwise be entitled.

It is the intention of the Legislature in enacting this chapter to provide for effective communication between all levels of government in this state and the people of this state who are precluded from utilizing public services because of language barriers.”

The Act generally requires state and local public agencies to provide interpreter and written document translation services in a manner that will ensure that LEP individuals have access to important government services. Agencies may employ bilingual staff, and translate documents into additional languages representing the clientele served by the agency. Public agencies also must conduct a needs assessment survey every two years documenting the items listed in Government Code section 7299.4, and develop an implementation plan every year that documents compliance with the Act. You may access a copy of this law at the following url: http://www.spb.ca.gov/bilingual/dymallyact.htm
FACULTY LIST

Course Chair

Lionel N. Metz, MD
Pediatric and Adult Spine Surgeon
Associate Professor of Orthopaedic Surgery
University of California, San Francisco
San Francisco, CA

Kyle A. Mitsunaga, MD
Assistant Professor of Orthopaedic Surgery, University of Hawaii
Medical Director, Spine Surgery, Queens Medical Center
Honolulu, HI

Lee A. Tan, MD
Assistant Professor of Neurosurgery
UCSF Medical Center
San Francisco, CA

Honored Faculty

Vincent Traynelis, MD
Professor of Neurosurgery
Vice-Chair Department of Neurosurgery
Rush University Medical Center

Alexander Vaccaro, MD, PhD
Professor of Orthopaedic Surgery and Neurosurgery
President, Rothman Orthopaedic Institute

Course Faculty

Christopher P. Ames, MD
Professor of Neurological Surgery and Orthopaedic Surgery
Director of Spinal Deformity & Spine Tumor Surgery
Co-director, Spinal Surgery and UCSF Spine Center
Director, California Deformity Institute
Director, Spinal Biomechanics Laboratory

Sigurd Berven, MD
Professor of Orthopaedic Surgery; Chief of Orthopaedic Spine Service

Aaron Clark, MD, PHD
Associate Professor of Neurological Surgery
UCSF

Major William R.Y. Carlton Jr., MD
MAJ, USA
Staff Neurosurgeon
Tripler Army Medical Center

Vedat Deviren, MD
Professor, Clinical Orthopaedic
UCSF Department of Orthopaedic Surgery

Graham Fedorak, MD
Pediatric Orthopaedic Surgery and Scoliosis Surgery
Kapi’olani Medical Center for Women and Children
Honolulu, HI
Ashraf El Naga, MD
Assistant Professor
UCSF/ZSFGH Department of Orthopaedic Surgery

Ricardo Fontes, MD, PhD
Associate Professor of Neurosurgery
Rush University Medical Center

Serena S. Hu, MD
Professor and Vice Chair
Chief, Spine Service

Yashar Javidan, MD
Associate Professor
Adult & Pediatric Spine Surgery
Spine Fellowship Director
UC Davis & Shriners Hospital for Childrens

Emmanuel Menga, MD
Associate Professor of Orthopaedics & Neurosurgery
Louis A. Goldstein Spine Surgery Fellowship Director
Associate Program Director, Orthopaedic Residency
University of Rochester School of Medicine and Dentistry
Rochester, NY

Jamal McClendon Jr., MD
Assistant Professor
Mayo Clinic Arizona
Phoenix Children's Hospital
Phoenix, Arizona

Praveen V. Mummaneni, MD, MBA
Joan O'Reilly Endowed Professor of Spine Surgery
Vice Chair, Department of Neurosurgery
Co-director of UCSF Spine Center
San Francisco, CA

Thomas Noh, MD
Clinical Assistant Professor
Division of Neurosurgery
University of Hawaii, John A Burns School of Medicine
Honolulu, HI

Sina Pourtaheri, MD
Spine Surgeons
Gulf Coast Orthopaedics
Houma, Louisiana

Bobby Tay, MD
Professor of Orthopaedic Surgery

Alekos Theologis, MD
Assistant Professor, UCSF Department of Orthopaedic Surgery
Spine

Alexander Tuchman, MD
Assistant Professor of Neurosurgery
Cedars-Sinai Medical Center
The following individuals have disclosed relevant financial relationships with ineligible companies whose primary business is producing, marketing, selling, re-selling, or distributing healthcare products used by or on patients:

### Christopher Ames, MD
- **Royalties/Holder of Intellectual Property Rights**
- **Stryker**
- **Biomet Zimmer Spine**
- **DePuy Synthes**
- **Nuvasive**
- **Next Orthosurgical**
- **K2M**
- **Medicrea**
- **Medtronic**
- **Agada Medical**
- **Carlsmed**
- **Titan Spine**
- **Operative Neurosurgery, Neurospine**
- **SRS**

### Sigurd Berven, MD
- **Consultant**
- **Stryker**
- **Globus**
- **Innovasis**
- **Accelus**
- **Camber**
- **Greensun Medical**
- **Novapproach**

### Aaron Clark, MD
- **Consultant**
- **Nuvasive**

### Vedat Deviren, MD
- **Consultant**
- **ATEC Spine**
- **NuVasive**
- **Medtronic**
- **ZimmerBiomet**
- **Seaspine**
- **Omega**
- **AO Spine**

### Ricardo Fontes, MD
- **Royalties/Holder of Intellectual Property Rights, Consultant**
- **Globus Medical**

### Yashar Javidan, MD
- **Grant/Research Support, Consultant**
- **NuVasive**
- **alphatec**
- **Stryker**
- **medtronic**
- **AO Spine**

### Emanuel Menga, MD
- **Grant/Research Support, Consultant**
- **Globus Medical**
- **Evolution Spine**
- **AOSpine**

### Lionel Metz, MD
- **Royalties/Holder of Intellectual Property Rights, Consultant**
- **Evolution Spine**
- **Alphatec Spine**
- **Medacta**
Consultant
Jamal McClendon, MD
Advisor or Reviewer
SeaSpine
Praveen Mummaneni, MD
Grant/Research Support
AO Spine
Consultant
DePuy Spine
Consultant
Globus
Consultant
Stryker
Stock Shareholder (excluding mutual funds)
Spinefinity/ISD
Grant/Research Support
ISSG
Grant/Research Support
NREF
Thomas Noh, MD
Consultant
spinal elements
Lee Tan, MD
Consultant
Medtronic
Consultant
Stryker
Consultant
Accelus
Bobby Tay, MD
Consultant
Stryker
Consultant
NuVasive
Grant/Research Support
Medtronic
Grant/Research Support
Omega
Consultant
ZimmerBiomet
Consultant
DePuy
Alekos Theologis, MD
Consultant
Depuy Spine
Consultant,Royalties/Holder of Intellectual Property Rights
Alphatec
Consultant
Surgalign
Consultant
Stryker/K2M
Consultant
Ulrich Medical
Consultant
Icotec
Consultant
Restor3D
Consultant
SpineArt
Vincent Traynelis, MD
Royalties/Holder of Intellectual Property Rights,Consultant
Medtronic
Consultant
NuVasive
Alex Vaccaro, MD
Stock Shareholder (excluding mutual funds)
Advanced Spinal Intellectual Properties
Royalties/Holder of Intellectual Property Rights
Aesculap
Independent Contractor
AO Spine
Royalties/Holder of Intellectual Property Right, Stock Shareholder (excluding mutual funds)
Atlas Spine
Stock Shareholder (excluding mutual funds)
Avaz Surgical
Stock Shareholder (excluding mutual funds)
AVKN Patient Driven Care
Stock Shareholder (excluding mutual funds)
Bonovo Orthopaedics
Stock Shareholder (excluding mutual funds)
Computational Biodynamics
Stock Shareholder (excluding mutual funds)
Cytonics
Stock Shareholder (excluding mutual funds)
Deep Health
Stock Shareholder (excluding mutual funds)
Dimension Orthotics, LLC
Stock Shareholder (excluding mutual funds)
Electrocore
Stock Shareholder (excluding mutual funds)
Elsevieri
Royalties/Holder of Intellectual Property Rights
Expert testimony
Independent Contractor
Flagship Surgical
Stock Shareholder (excluding mutual funds)
FlowPharma
Royalties/Holder of Intellectual Property Rights, Stock Shareholder (excluding mutual funds)
Globus
Stock Shareholder (excluding mutual funds)
Innovative Surgical Design
Stock Shareholder (excluding mutual funds)
Jaypee
Royalties/Holder of Intellectual Property Rights

Serena S. Hu, MD
Board Member
Consultant
Royalties/Holder of Intellectual Property Rights

All of the relevant financial relationships listed for these individuals have been mitigated. All others in control of content have no relevant financial relationships with ineligible companies.

Major William R.Y. Carlton, MD
Graham Fedorak MD
Kyle Mitsunaga, MD
Sina Pouraheri, MD
Alexander Tuchman, MD
Ashraf El Naga, MD

This UCSF CME educational activity was planned and developed to: uphold academic standards to ensure balance, independence, objectivity, and scientific rigor; adhere to requirements to protect health information under the Health Insurance Portability and Accountability Act of 1996 (HIPAA); and, include a mechanism to inform learners when unapproved or unlabeled uses of therapeutic products or agents are discussed or referenced.

This activity has been reviewed and approved by members of the UCSF CME Governing Board in accordance with UCSF CME accreditation policies. Office of CME staff, planners, reviewers, and all others in control of content have disclosed no relevant financial relationships.
### Wednesday, July 13, 2022

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:00 pm</td>
<td>Registration</td>
<td>Lionel Metz, MD</td>
</tr>
<tr>
<td>3:15</td>
<td>Welcome and Introductions</td>
<td>Lee Tan, MD, Kyle Mitsunaga, MD</td>
</tr>
<tr>
<td>3:20</td>
<td>Honored Speaker Introduction</td>
<td>Alex Vaccaro, MD</td>
</tr>
<tr>
<td>3:25</td>
<td>Return to Play Criteria Following Cervical Trauma in Collision Athletes</td>
<td>Ashraf El Naga, MD</td>
</tr>
<tr>
<td>3:55</td>
<td>Pediatric Spine Trauma: Management, Operative Indications, and Technical Considerations</td>
<td>Major William R.Y. Carlton, MD</td>
</tr>
<tr>
<td>4:15 pm</td>
<td>Update on Adult Thoracolumbar Spine Trauma</td>
<td>Ricardo Fontes, MD</td>
</tr>
<tr>
<td>4:35 pm</td>
<td>Evaluation and Treatment of Cervical Deformities</td>
<td>Vincent Traynelis, MD</td>
</tr>
<tr>
<td>4:55 pm</td>
<td>Honored Speaker Introduction</td>
<td></td>
</tr>
<tr>
<td>5:00 pm</td>
<td>Contemporary Management of Odontoid Fractures</td>
<td></td>
</tr>
<tr>
<td>5:30 pm</td>
<td>Q&amp;A</td>
<td></td>
</tr>
<tr>
<td>5:45 pm</td>
<td>Case Presentation and Discussion</td>
<td></td>
</tr>
<tr>
<td>6:15 pm</td>
<td>Adjourn: Luau Reception</td>
<td></td>
</tr>
</tbody>
</table>

### Thursday, July 14, 2022

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00 am</td>
<td>Continental Breakfast</td>
<td></td>
</tr>
<tr>
<td>7:30</td>
<td>Welcome and Introductions</td>
<td></td>
</tr>
<tr>
<td>7:35</td>
<td>Artificial Intelligence and Predictive Modeling in Spine Surgery</td>
<td>Christopher Ames, MD</td>
</tr>
<tr>
<td>7:55</td>
<td>Operative and Non-operative Strategies for Early Onset Scoliosis: Casting, Traction, and Growth Friendly Instrumentation</td>
<td>Graham Fedorak MD</td>
</tr>
<tr>
<td>8:15</td>
<td>Honored Speaker Introduction</td>
<td></td>
</tr>
<tr>
<td>8:20</td>
<td>The Evolution of Treatment for Pediatric Deformity</td>
<td>Serena S. Hu, MD</td>
</tr>
<tr>
<td>8:50</td>
<td>Pediatric Deformities with High Morbidity in Adulthood: When to Treat and When to Observe</td>
<td>Sigurd Berven, MD</td>
</tr>
<tr>
<td>9:10</td>
<td>Case Presentation and Discussion</td>
<td></td>
</tr>
<tr>
<td>9:15</td>
<td>Q&amp;A</td>
<td></td>
</tr>
<tr>
<td>9:35</td>
<td>Coffee Break</td>
<td></td>
</tr>
<tr>
<td>9:55</td>
<td>Honored Speaker Introduction</td>
<td></td>
</tr>
<tr>
<td>10:30</td>
<td>Evaluation and Treatment of C-5 Palsy</td>
<td>Vincent Traynelis, MD</td>
</tr>
<tr>
<td>10:45</td>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td>11:00</td>
<td>Emerging Technology in Spine Surgery: Augmented Reality and Enhanced Surgical Navigation</td>
<td>Thomas Noh, MD</td>
</tr>
<tr>
<td>11:20</td>
<td>The Prone Lateral Interbody Fusion, Indications and Advantages</td>
<td>Vedat Deviren, MD</td>
</tr>
<tr>
<td>11:40</td>
<td>Case Discussion</td>
<td></td>
</tr>
<tr>
<td>12:10 pm</td>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td>1:05</td>
<td>Adolescent Idiopathic Scoliosis Choosing Levels and Achieving a 3-D Correction</td>
<td>Jamal McClendon, MD</td>
</tr>
<tr>
<td>1:30</td>
<td>Deciding When to Use 3-Column Osteotomies vs Multiple Posterior Column Osteotomies for Deformity Correction</td>
<td>Alexander Tuchman, MD</td>
</tr>
<tr>
<td>1:50</td>
<td>Proximal Junction Kyphosis: Etiology, Risk Factors, and Prevention- Updates with Pediatric Focus</td>
<td>Emanuel Menga, MD</td>
</tr>
<tr>
<td>2:10</td>
<td>Honored Speaker Introduction</td>
<td></td>
</tr>
<tr>
<td>2:15</td>
<td>Contemporary Management of Postoperative Spinal Infections</td>
<td>Alex Vaccaro, MD</td>
</tr>
<tr>
<td>2:45</td>
<td>Q&amp;A and Case Discussion</td>
<td></td>
</tr>
<tr>
<td>3:00 pm</td>
<td>Adjourn</td>
<td></td>
</tr>
</tbody>
</table>
### Friday, July 15, 2022

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00 am</td>
<td>Continental Breakfast at Royal Hawaiian, Depart at 7:30 am for Cadaver Lab</td>
</tr>
<tr>
<td>7:30</td>
<td>Cadaver Lab</td>
</tr>
<tr>
<td>12:00 pm</td>
<td>Lunch</td>
</tr>
<tr>
<td>1:00</td>
<td>Cadaver Lab</td>
</tr>
<tr>
<td>4:30 PM</td>
<td>Adjourns</td>
</tr>
</tbody>
</table>

8 CME

**Bio-skills Stations to include:**
- Anterior, lateral, and oblique Lumbar Interbody Fusion
- Thoracolumbar pedicle subtraction osteotomy/vertebral column resection
- Pelvic Fixation
- Transforaminal lumbar Interbody Fusion for Deformity
- Free hand Posterior Pedicle Screw Fixation/Posterior Column Osteotomy
- Anterior Spinal Instrumentation/Tethering
- Cervical Anterior and Posterior Instrumentation

### Saturday, July 16, 2022

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00 am</td>
<td>Continental Breakfast</td>
</tr>
<tr>
<td>7:30</td>
<td>Distinguishing Structural Sagittal Imbalance for Pseudo-sagittal Imbalance Related to Spinal Stenosis Sina Pourtaheri, MD</td>
</tr>
<tr>
<td>7:50</td>
<td>Honored Speaker Introduction</td>
</tr>
<tr>
<td>7:55</td>
<td>Treatment of Spondylolisthesis in Pediatric and Adult Patients Serena S. Hu, MD</td>
</tr>
<tr>
<td>8:25</td>
<td>Minimally Invasive Deformity Correction, Indications and Contraindications Praveen Mummaneni, MD</td>
</tr>
<tr>
<td>8:45</td>
<td>Treatment of Degenerative Lumbar Deformities, When is Addressing the Fractional Curve Enough? Bobby Tay, MD</td>
</tr>
<tr>
<td>9:05</td>
<td>Case Discussion</td>
</tr>
<tr>
<td>9:30</td>
<td>Essentials of Resection and Reconstruction for Tumors of the Spinal Column Alekos Theologis, MD</td>
</tr>
<tr>
<td>9:50</td>
<td>Correction Strategies in Pediatric Scoliosis Yashar Javidan, MD</td>
</tr>
<tr>
<td>10:10</td>
<td>Case Discussion</td>
</tr>
<tr>
<td>10:45</td>
<td>Break</td>
</tr>
<tr>
<td>11:05</td>
<td>Less Invasive Lumbar Interbody Fusion LLIF, Lateral ALIF Aaron Clark, MD</td>
</tr>
<tr>
<td>11:25</td>
<td>Case Discussion &amp; Question and Answer</td>
</tr>
<tr>
<td>12:00 pm</td>
<td>Course Adjourns</td>
</tr>
<tr>
<td>Stations / Position</td>
<td>Instructor</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Cadaver #1</td>
<td>Vedat Deviren, M.D.</td>
</tr>
<tr>
<td></td>
<td>Christopher Ames, M.D.</td>
</tr>
<tr>
<td>Cadaver #2</td>
<td>Serena Hu, M.D.</td>
</tr>
<tr>
<td></td>
<td>Aaron Clark, M.D., PhD.</td>
</tr>
<tr>
<td>Cadaver #3</td>
<td>Sigurd Berven, M.D.</td>
</tr>
<tr>
<td></td>
<td>Vincent Traynelis</td>
</tr>
<tr>
<td>Cadaver #4</td>
<td>Praveen Mummaneni, M.D.</td>
</tr>
<tr>
<td></td>
<td>Menga Emmanuel, M.D.</td>
</tr>
<tr>
<td>Cadaver #5</td>
<td>Alex Vaccaro, M.D</td>
</tr>
<tr>
<td></td>
<td>Ashraf El Naga</td>
</tr>
</tbody>
</table>
Return to Play Criteria Following Cervical Spine Injuries in Collision Sports

Alexander R. Vaccaro, MD, PhD, MBA
Professor and Chairman
Thomas Jefferson University
President of the Rothman Institute
Philadelphia, Pa

Disclosures

• Grant Support/ Royalties/Stock options/Private Contractor:
  • President: Rothman Institute
  • AAOS Board Member
Cervical Sports Injury Study

- NEISS (National Electronic Injury Surveillance System) database
  - Collects information on patients presenting to 100 hospitals across the United States
  - 2000 to 2015
  - Incidence of cervical spine fractures increased 35%
  - Incidence due to cycling increased 300%-Increased dramatically since 2000
  - American football is leading sport-related cause of neck injury in the United States

https://www.icpsr.umich.edu/web/NACJD/series/198

Most Common Causes of Cervical Fractures
Epidemiology

- 35-49% of collision sport spine injuries affect the cervical spine
  - 46% nerve injuries
  - 22% muscle injuries
  - 6% disc injuries
  - 2% fractures
  - 2% contusions

Schroeder, Neurosurgery, 2020

Neuro Injury

- Common with:
  - Trampoline
  - Football
  - Water sports
  - Gymnastics
  - Rugby
  - Ice Hockey
  - Wrestling
Epidemiology

- 9-12% of spinal cord injuries per year attributable to sports
- 7-10% of injuries in NFL involve the head/neck/spine—not including concussions
- NFL spine injury incidence rates: 148.26/100,000 athlete-exposures (AEs)
  - College-level football 3.55/1000 AEs
- 2208 spinal injuries in NFL from 2000 to 2010, 44.7% were cervical spine injuries
  - 23.4 days missed/injury

Schröder, Neurosurgery, 2020

Spear Tackling

Spearing
- 30° cervical flexion
- “Segmented column”
**Proper Technique**

- Head Up - “See What You Hit”
- Knees Bent at Impact
- Drive Through with Legs

**Level of Cervical Disc Herniation**

Radhakrishnan, Brain 1994

<table>
<thead>
<tr>
<th>Level of Cervical Disc Herniation</th>
<th>General population</th>
<th>NFL players</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C7T1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cervical Cord Neuropraxia CCN

- 50% will experience a second CCN
- 14 MM Spinal Cord diameter (MRI) → 5% recurrence
- 9 MM Spinal Cord diameter (MRI) → 50% recurrence
- Controversy-One episode not predictive of subsequent permanent neurologic loss

Torg, Current Sports Medicine Reports, 2002

The Impact of a Cervical Spine Diagnosis on the Careers of National Football League Athletes

Gregory D. Schroeder, MD,* T. Sean Lynch, MD,† Daniel B. Gibbs, MD,* Ian Chow, BS,* Mark W. LaBelle, BS,* Alpesh A. Patel, MD, FACS,* Jason W. Savage, MD,* Gordon W. Nuber, MD,‡ and Wellington K. Hsu, MD*

- Medical evaluations and imaging reports of American football athletes during the combine
- 2965 athletes attended the NFL combine between 2003 and 2011
- Out of all participants, 143 players (4.8%) were identified as having a preexisting cervical spine diagnosis
Outcomes-Draft

- 7 players drafted with history surgery
  - 4 ACDF
  - 2 foraminotomy
  - 1 suboccipital craniectomy with C1 laminectomy
- No difference in career longevity or performance compared to matched controls

Schroeder, Spine, 2014
Outcomes

NFL players with CDH treated operatively compared to nonop:
• Greater percentage return to play (72 vs 46%)
• More games played (29.3 vs 14.7)
• Longer careers after injury (2.8 vs 1.5 yrs)
• 5.3% of players required revision surgery for adjacent level disease

Hsu, Spine. 2011

Spinal Cord Signal Changes

• 4 NFL athletes, 1 wrestler: traumatic neurapraxia, T2 increased signal
• 3/4 cleared to returned to play prior to achieving complete resolution of MRI T2 signal abnormality
• 2 that eventually returned to play did not experience further symptoms, 1 still had cord changes

Tempel, Neurosurgery, 2015
Role of MRI and RTP

- 10 pts, T2 signal change, transient cord injury w/stenosis. None treated surgically
- 6/10 had repeat transient spinal cord injury (1 - 36 months) regardless of return to play

Schroeder, Spine 2014
Bailes, Neurosurg 2005
Brigham, Spine 2013

Questions in setting of CCN/SCI

1. Does occurrence vary if wearing protective gear?
2. Does incidence, occurrence vary by position?
3. Can patients without canal stenosis/disc herniation return to play?
4. Can patients with canal stenosis/disc herniation return to play?
5. Can patients return to play after ACDF?
6. Are there clinical, sports related, imaging, or surgical factors predictive of recurrence?

Wong, Spine Line, 2016
Hutton, Global Spine Journal, 2016
Nagoshi, The Spine Journal, 2017
Return to play in athletes with spinal cord concussion: a systematic literature review

Narihito Nagoshi, MD, PhD,a,b, Lindsay Tetreault, PhD,a, Hiroaki Nakashima, MD,a,c, Aria Nouri, MD, MSc,a, Michael G. Fehlings, MD, PhD, FRCS, FACS,a,d,e

The Spine Journal 17 (2017) 291–302

• Systematic review
• Investigated predictors for the risk of SCC recurrence or SCI

Cervical Spinal Cord Neuropraxia

Class IV evidence. All high risk of bias.
• 2 studies - pts without stenosis-1 patient recurrent SCN after return to play
• 7 studies- pts with stenosis. Some patients with permanent neurologic deficits. > 50% experience a second episode of neurapraxia
• 3 studies - s/p ACDF. Several recurrent SCC due to herniation at adjacent levels
• Predictors- greater frequency recurrence with “long” duration of symptoms (>24 hours), Small Disc-level canal diameter and SC:VB ratio, Younger age (21.62±3.91 years vs. 25.39±6.02 years)
Return to Play Professional Athletes

Molinari, Global Spine Journal, 2016

Table 2  Frequency of return to play for professional athletes by sport

<table>
<thead>
<tr>
<th>Professional sport</th>
<th>Return to play</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rugby</td>
<td>74% (14/19)</td>
</tr>
<tr>
<td>Football*</td>
<td>73% (48/66)</td>
</tr>
<tr>
<td>Wrestling</td>
<td>100% (9/9)</td>
</tr>
<tr>
<td>Baseball</td>
<td>88% (7/8)</td>
</tr>
</tbody>
</table>

*Includes one collegiate-level football player.
RTP Recommendations

- (1) Restoration of full functional, pain-free range of motion of the cervical spine
- (2) Restoration of baseline cervical spine musculature strength against resistance
- (3) Absence of any focal neurological deficits

In the event of surgical fusion, the following condition must also be met:

- (4) Observation of radiographic evidence of solid arthrodesis

Huang 2016, Sports Health

<table>
<thead>
<tr>
<th>Clinical Recommendation</th>
<th>SORT Evidence Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return-to-play recommendations after spine injuries are widely variable, but at a minimum, general criterion should be met prior to resuming athletic participation. These criteria include the following: full strength, painless and full range of motion, and full strength without neurologic deficit.</td>
<td>c</td>
</tr>
<tr>
<td>Absolute contraindications to return to play for contact sports include but are not limited to: atlanto-occipital fusion, evidence of bony or ligamentous instability, symptomatic disc herniation, neurologic deficit, myelopathy, Arnold-Chiari malformation, and multifocal (2-3) spinal fusions.</td>
<td>c</td>
</tr>
</tbody>
</table>

There is a lack of consensus regarding specific return-to-play criteria after spine surgery and injury.

Management of Acute Subaxial Trauma and Spinal Cord Injury in Professional Collision Athletes

- Narrative review acute management of subaxial trauma and SCI
- Algorithm for RTP
### TABLE 1. Absolute Contraindications to Return-to-Play

<table>
<thead>
<tr>
<th>Injury</th>
<th>Level of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two or more episodes of transient cervical cord neuropraxia</td>
<td>IV</td>
</tr>
<tr>
<td>First episode of cervical spinal cord neuropraxia with persistent neurological deficits</td>
<td>IV</td>
</tr>
<tr>
<td>First episode of transient cervical spinal cord neuropraxia with radiographic evidence of spinal canal stenosis and increased T2-weighted MRI signal of the spinal cord, with or without a neurological deficits</td>
<td>III</td>
</tr>
<tr>
<td>Symptomatic disc herniation</td>
<td>IV</td>
</tr>
<tr>
<td>Stingers associated with persistent pain/weakness</td>
<td>IV</td>
</tr>
<tr>
<td>Any injury requiring fusion of 3 or more levels</td>
<td>V</td>
</tr>
<tr>
<td>Any fracture with a residual neurological deficit</td>
<td>IV</td>
</tr>
<tr>
<td>Any injury requiring occipital fusion</td>
<td>V</td>
</tr>
<tr>
<td>Any injury requiring C1–C2 fusion</td>
<td>V</td>
</tr>
<tr>
<td>Spear tackler’s spine</td>
<td>IV</td>
</tr>
<tr>
<td>Odontoid anomalies</td>
<td>IV</td>
</tr>
</tbody>
</table>

### TABLE 2. Relative Contraindications to Return-to-Play

<table>
<thead>
<tr>
<th>Injury</th>
<th>Level of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>First episode of cervical spinal cord neuropraxia with radiographic evidence of spinal canal stenosis, without increased T2-weighted MRI signal of the spinal cord or any focal neurological deficits</td>
<td>IV</td>
</tr>
<tr>
<td>First episode of cervical spinal cord neuropraxia with increased T2-weighted MRI signal of the spinal cord, without radiographic evidence of spinal canal stenosis or any focal neurological deficits</td>
<td>IV</td>
</tr>
<tr>
<td>Three or more stingers within the same season</td>
<td>V</td>
</tr>
<tr>
<td>Two-level healed ACDF</td>
<td>IV</td>
</tr>
<tr>
<td>Minimally displaced C1 ring fracture</td>
<td>IV</td>
</tr>
<tr>
<td>C2 compression fracture</td>
<td>IV</td>
</tr>
<tr>
<td>All other upper cervical spine fractures treated nonsurgically</td>
<td>IV</td>
</tr>
<tr>
<td>Upper cervical spine fractures requiring surgical stabilization excluding C1–C2 arthrodesis</td>
<td>IV</td>
</tr>
<tr>
<td>Isolated healed compression fracture of the subaxial cervical spine</td>
<td>IV</td>
</tr>
<tr>
<td>Isolated healed burst fracture of the subaxial cervical spine</td>
<td>IV</td>
</tr>
<tr>
<td>Healed fracture of the posterior bony (lateral mass or articular processes) excluding spinous or transverse process fractures of the subaxial cervical spine</td>
<td>IV</td>
</tr>
<tr>
<td>Pseudarthrosis</td>
<td>IV</td>
</tr>
</tbody>
</table>
• Delphi methodology
• 3 round survey study was conducted with CSRS and NFL team physicians
• Establish consensus guidelines for cervical spine injury management in collision sport athletes
RTP: Work Up

- Athletes with prior non-op or operative treatment for cervical spine should undergo a screening MRI prior to contact sports
  - 78.9% agreement
- Athletes who experience 1st stinger with rapid resolution do not require an MRI, however MRI should be obtained after 2nd stinger
  - 69.9% agreement
- Athletes symptomatic <5 min following a stinger are allowed to RTP, but for symptoms >5 min RTP taken on a case-by-case basis
  - 85.5% agreement

RTP: Cervical Canal Stenosis

- Collision athlete after an initial episode of transient paralysis from CSI, asymptomatic athletes with NO T2-signal changes
  - 90.5% agreement
- Canal diameter >10 mm allowed to RTP
- Canal diameter <10 mm case-by-case basis
RTP: Cervical Canal Stenosis

• Collision athlete after an initial episode of transient paralysis from CSI, asymptomatic athletes with **RESOLVED** T2-signal changes
• 81.3% agreement
  • Canal diameter >13 mm allowed to RTP
  • Canal diameter between 10 and 13 mm should be considered on a case-by-case basis
  • Canal diameter <10 mm should not RTP

RTP: Cervical Canal Stenosis

• Collision athlete after an initial episode of transient paralysis from CSI, asymptomatic athletes with **CONTINUED** T2-signal changes
• 68.3% agreement
  • Canal diameter >13 mm RTP on case-by-case basis
  • Canal diameter <13 mm should not RTP
RTP: Cervical Spine Fracture/Surgery

- Asymptomatic athletes with a solid fusion after fracture with no instability and NO T2-signal change
- 98.6% agreement
  - Are allowed to RTP

- Asymptomatic athletes following 1 level PCF
- 68.6% agreement
  - Are allowed to RTP

RTP: Cervical Spine Injury following Surgery

- Asymptomatic athlete with NO T2-signal change
- 84.4% agreement
  - Solid 1-2 level ACDF allowed to RTP
  - 3-level ACDF should not RTP
RTP: Cervical Spine Injury/Surgery

- Asymptomatic athlete with **CONTINUED** T2-signal change
- 81.9% agreement
  - 1-level ACDF RTP on case-by-case basis
  - Solid 2-3 level ACDF should not RTP

RTP: Cervical Spine Injury/Surgery

- Asymptomatic athlete with **NO** T2-signal change
- 72.9% agreement
  - **Corpectomy** - RTP on a case-by-case basis
RTP: Cervical Spine Injury/Surgery/Pseudarthrosis

- Athletes with pseudarthrosis
- 59.5% agreement
  - 1-level ACDF RTP on case-by-case basis
  - 2-3 level ACDF should not RTP

RTP: Pseudarthrosis

- NHL player RTP at 6.7 months
- Played for 4 additional seasons
- Acute injury that caused persistent neck pain
- Imaging revealed a nonunion

- Underwent posterior instrumentation and fusion and returned to play 7.8 months later

Watkins 2018, OJSM
Return to Sports After Cervical Total Disc Replacement

Andreas Reinke, Michael Behr, Alexander Preuss, Jimmy Villard, Bernhard Meyer, Florian Ringel

- 45 pro/semi-pro/recreational athletes
- All returned to previous level of play

Position

Defensive Backs--25% of all cervical disc herniation

Linebackers --25% of all cervical disc herniation
Summary of the Evidence: Stenosis

- Pain free range of motion, stability, normal neurologic exam, and solid fusion are necessary components of the RTP decision process
- RTP
  - WITHOUT T2-signal changes on cervical MRI, WITHOUT evidence of absolute cervical stenosis
  - RESOLVED T2-signal changes and WITHOUT any evidence of cervical spine stenosis
- RTP case by base
  - NO MRI changes and WITH evidence of absolute cervical stenosis
  - Resolved MRI changes and relative stenosis
  - CONTINUED T2-signal changes and without evidence of any cervical stenosis
- No RTP
  - PERSISTENT T2-signal changes and any form of cervical stenosis
  - RESOLVED MRI changes and absolute cervical stenosis

Summary of Evidence: Fusion

- RTP
  - Healed fractures without instability or MRI changes after 1-level ACDF or 1-level PCF with solid fusion
- RTP Case by Case
  - 1-level ACDF with CONTINUED T2-signal changes
  - Corpectomy or posterior cervical surgery >1 level
- No RTP
  - 3-level ACDF athletes should not RTP
- No consensus
  - 2-level ACDF
Conclusion

- In the absence of strong literature, clinical expertise and professional opinion must be used to develop consensus statements and provide guidance to the treating physician.
THORACOLUMBAR SPINE TRAUMA

WILLIAM R. Y. CARLTON JR., MD

Disclosures

• No conflicts of interest to disclose
• The views and opinions presented here are my own, they do not reflect those of the US Army or Department of Defense
Introduction

- Thoracolumbar spine fractures account for around 90% of all spinal fractures
- Due to the rigidity of the costotransverse joints of the thoracic spine, the fulcrum of movement at the time of trauma is in the thoracolumbar segment, where most of these fractures occur
- ~50% occur from fall from height
- ~45% occur from traffic accidents
- ~5% are caused by direct trauma

Case

- 22 M fell down stairs. Ambulatory afterward but with severe mid back pain.
- After a few days, presented to PCP.
- After getting XR, PCP sent to ER
- You are called after CT scan obtained
- He is neurologically intact on exam

- What do you do?
**TLICS**  

<table>
<thead>
<tr>
<th>Predicts</th>
<th>Need for surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>nonsurgical</td>
</tr>
<tr>
<td>&gt;4</td>
<td>surgical</td>
</tr>
</tbody>
</table>

**Thoracolumbar injury classification and severity score: a new paradigm for the treatment of thoracolumbar spine trauma**

First published in 2005

“Current classification schemes of these injuries can be either too simplified or overly complex for clinical use.”

Rates three independent predictors and the score helps guide when to operate

Subsequently validated with several studies

---

**COMPRESSION**

**Compression 1 pnt**

- Simple compression
- Wedge deformity

---

**TLICS**  

<table>
<thead>
<tr>
<th>Predicts</th>
<th>Need for surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>nonsurgical</td>
</tr>
<tr>
<td>&gt;4</td>
<td>surgical</td>
</tr>
</tbody>
</table>

---

**Morphology**

<table>
<thead>
<tr>
<th>Immediate stability</th>
<th>TLICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression</td>
<td>1</td>
</tr>
<tr>
<td>Burst</td>
<td>2</td>
</tr>
<tr>
<td>Translation/rotation</td>
<td>3</td>
</tr>
<tr>
<td>Distraction</td>
<td>4</td>
</tr>
</tbody>
</table>

**Integrity of PLC**

<table>
<thead>
<tr>
<th>Longterm stability</th>
<th>TLICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact</td>
<td>0</td>
</tr>
<tr>
<td>Suspected</td>
<td>2</td>
</tr>
<tr>
<td>Injured</td>
<td>3</td>
</tr>
</tbody>
</table>

**Neurological status**

<table>
<thead>
<tr>
<th>Neurological status</th>
<th>TLICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact</td>
<td>0</td>
</tr>
<tr>
<td>Nerve root</td>
<td>2</td>
</tr>
<tr>
<td>Complete cord</td>
<td>2</td>
</tr>
<tr>
<td>Incomplete cord</td>
<td>3</td>
</tr>
<tr>
<td>Cauda equina</td>
<td>3</td>
</tr>
</tbody>
</table>

**Predicts**

<table>
<thead>
<tr>
<th>Predicts</th>
<th>Need for surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>nonsurgical</td>
</tr>
<tr>
<td>&gt;4</td>
<td>surgical</td>
</tr>
</tbody>
</table>

---

**Morphology**

<table>
<thead>
<tr>
<th>Immediate stability</th>
<th>TLICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression</td>
<td>1</td>
</tr>
<tr>
<td>Burst</td>
<td>2</td>
</tr>
<tr>
<td>Translation/rotation</td>
<td>3</td>
</tr>
<tr>
<td>Distraction</td>
<td>4</td>
</tr>
</tbody>
</table>

**Integrity of PLC**

<table>
<thead>
<tr>
<th>Longterm stability</th>
<th>TLICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact</td>
<td>0</td>
</tr>
<tr>
<td>Suspected</td>
<td>2</td>
</tr>
<tr>
<td>Injured</td>
<td>3</td>
</tr>
</tbody>
</table>

**Neurological status**

<table>
<thead>
<tr>
<th>Neurological status</th>
<th>TLICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact</td>
<td>0</td>
</tr>
<tr>
<td>Nerve root</td>
<td>2</td>
</tr>
<tr>
<td>Complete cord</td>
<td>2</td>
</tr>
<tr>
<td>Incomplete cord</td>
<td>3</td>
</tr>
<tr>
<td>Cauda equina</td>
<td>3</td>
</tr>
</tbody>
</table>

**Predicts**

<table>
<thead>
<tr>
<th>Predicts</th>
<th>Need for surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>nonsurgical</td>
</tr>
<tr>
<td>&gt;4</td>
<td>surgical</td>
</tr>
</tbody>
</table>
BURST

Burst 2 pnts

- Compression with retro-pulsion of superoposterior body fragment

TLICS 3 independent predictors

<table>
<thead>
<tr>
<th></th>
<th>Morphology immediate stability</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Compression</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Radiographs</td>
</tr>
<tr>
<td></td>
<td>Burst</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CT</td>
</tr>
<tr>
<td></td>
<td>Translation/Rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Distraction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td>2</td>
<td>Integrity of PLC, long term stability</td>
<td>Intact</td>
<td>Suspected</td>
<td>Injured</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Intact</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Nerve root</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Complete cord</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Incomplete cord</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Cauda equina</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td>3</td>
<td>Neurological status</td>
<td></td>
<td></td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Intact</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Nerve root</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Complete cord</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Incomplete cord</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Cauda equina</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td>Predicts</td>
<td>Need for surgery</td>
<td>0 – 3</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Non-surgical surgeon’s choice</td>
</tr>
</tbody>
</table>

TRANSLATION/ROTATION

Translation/rotation 3 pnts

- Rotatory/shearing
- Anterior or lat displacement
- Facet joint displacement

TLICS 3 independent predictors

<table>
<thead>
<tr>
<th></th>
<th>Morphology immediate stability</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Compression</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Radiographs</td>
</tr>
<tr>
<td></td>
<td>Burst</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CT</td>
</tr>
<tr>
<td></td>
<td>Translation/Rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Distraction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td>2</td>
<td>Integrity of PLC, long term stability</td>
<td>Intact</td>
<td>Suspected</td>
<td>Injured</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Intact</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Nerve root</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Complete cord</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Incomplete cord</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Cauda equina</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td>3</td>
<td>Neurological status</td>
<td></td>
<td></td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Intact</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Nerve root</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Complete cord</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Incomplete cord</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td></td>
<td>Cauda equina</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MRI</td>
</tr>
<tr>
<td>Predicts</td>
<td>Need for surgery</td>
<td>0 – 3</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Non-surgical surgeon’s choice</td>
</tr>
</tbody>
</table>

> 4 | Surgical |
DISTRACTION

- Horizontal fracture of posterior elements
- Separation of posterior elements

<table>
<thead>
<tr>
<th>TLICS</th>
<th>3 independent predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Morphology immediate stability</td>
</tr>
<tr>
<td>2</td>
<td>Integrity of PLC long term stability</td>
</tr>
<tr>
<td>3</td>
<td>Neurological status</td>
</tr>
<tr>
<td></td>
<td>Predicts Need for surgery</td>
</tr>
<tr>
<td></td>
<td>0-3 nonsurgical surgeon’s choice</td>
</tr>
<tr>
<td></td>
<td>4 surgical</td>
</tr>
</tbody>
</table>

AO Spine Thoracolumbar Injury Classification System

- Published in 2013
- Goal was to address what was felt to be shortcoming of TLICS:
  - "The main drawback of this system is that it relies on interpretation of stability of the posterior ligamentous complex on MRI, which inherently varies between surgeons"
AO Spine Classification

• Treatment algorithm based on survey of AO Spine members
  • 3 or less: conservative management
  • 4-5: operative or non-operative management acceptable
  • >5: surgical intervention recommended

OK, so I’ve decided to operate...

• Considerations:
  • How many levels?
  • Location of fracture relative to junctions (Cervicothoracic, thoracolumbar, lumbosacral)
  • Anterior versus posterior versus combined approach
  • Is bone quality an issue? (osteoporosis, DISH, Ankylosing Spondylitis)
In 1994 paper by McCormack et al., 28 consecutive patients with three-column fractures were stabilized by short segment (1 above/1 below) posterior instrumented fusion.

Of the 28 patients, 10 developed hardware failure. They created a classification system to predict who would fail and require anterior support. Using their score:

- 6 or less, a posterior approach alone was recommended
- >6, they recommended a second staged anterior approach to prevent instrumentation failure

### The Load Sharing Classification of Spine Fractures

**Table 1. McCormack Load-sharing Classification.**

<table>
<thead>
<tr>
<th>Score</th>
<th>1 Point</th>
<th>2 Points</th>
<th>3 Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression</td>
<td>30%</td>
<td>30–60%</td>
<td>&gt;60%</td>
</tr>
<tr>
<td>Apposition of fragments</td>
<td>1 mm</td>
<td>2 mm</td>
<td>&gt;2 mm</td>
</tr>
<tr>
<td>Deformity correction</td>
<td>$\Delta^3$</td>
<td>$\Delta^4$</td>
<td>$\Delta^5$</td>
</tr>
</tbody>
</table>

15
16
• How about using a longer posterior construct instead?
  • Avoid morbidity of a thoracic or lumbar corpectomy

<table>
<thead>
<tr>
<th>Type of arthrodesis</th>
<th>Number of patients</th>
<th>Implant failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 and 1</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>2 and 2</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>3 and 2</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>2</td>
</tr>
</tbody>
</table>

• Avanzi et al. in 2010:
  • 22 patients with thoracolumbar burst fractures, all underwent posterior only instrumented fusion with constructs greater than 1 above / 1 below
  • “The classification of McCormack et al is not applicable to patients who undergo operations consisting of longer posterior arthrodesis... No instrumentation failures were seen in cases with strategies with two levels above and two levels below the fracture.”

• So: LSC >6 can equal either staged anterior approach OR at more points of fixation posteriorly

Let’s apply this to some cases
Case

- HPI: 19 F with severe low back pain after MVC
- CT: L5 burst fracture
- EXAM:

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>LEFT</th>
<th>RIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deltoid (C5)</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Biceps (C5, C6)</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Triceps (C5, C7)</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Finger Flexion (C8)</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Finger Abduction (T1)</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Hip Flexion (L2, L3)</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Knee Extension (L3, L4)</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Dorsiflexion (L4, L5)</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>EHL (L5)</td>
<td>5/5</td>
<td>3/5</td>
</tr>
<tr>
<td>Plantarflexion (S1, S2)</td>
<td>5/5</td>
<td>5/5</td>
</tr>
</tbody>
</table>
Case

- TLICS: 4*
  - Burst: 2
  - PLC: 0*
  - Neuro: 2
  - *No MRI
LSC: 6 (30-60%, >2 mm apposition, little correction)  
LSC: >6 for more than 1 up / 1 down

**TABLE 1. McCormack Load-sharing Classification.**

<table>
<thead>
<tr>
<th>Score</th>
<th>1 Point</th>
<th>2 Points</th>
<th>3 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comminution</td>
<td>30%</td>
<td>30-60%</td>
<td>&gt;60%</td>
</tr>
<tr>
<td>Apposition of fragments</td>
<td>1 mm</td>
<td>2 mm</td>
<td>&gt;2 mm</td>
</tr>
<tr>
<td>Deformity correction</td>
<td>3°</td>
<td>4°-9°</td>
<td>&gt;10°</td>
</tr>
</tbody>
</table>

**PLAN:** L4-S1 fusion
Case

• HPI: 49 M fell from 40 ft while trimming a tree. Had severe LBP and RLE pain.

• CT: L4 burst fracture, L5 spondylolyis with spondylolisthesis, L1 compression fx

• EXAM:
  – 5/5 BLE
**Case**

- TLICS: 4*
  - Burst: 2
  - PLC: 0?
  - Neuro: 2
  - *No MRI

<table>
<thead>
<tr>
<th>TLICS</th>
<th>3 independent predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Morphology immediate stability</td>
</tr>
<tr>
<td>2</td>
<td>Integrity of PLC longterm stability</td>
</tr>
<tr>
<td>3</td>
<td>Neurological status</td>
</tr>
<tr>
<td></td>
<td>Predicts</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Point allocation for morphologic groups:

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A-compression fractures</td>
<td></td>
</tr>
<tr>
<td>A0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>1</td>
</tr>
<tr>
<td>A2</td>
<td>2</td>
</tr>
<tr>
<td>A3</td>
<td>3</td>
</tr>
<tr>
<td>A4</td>
<td>5</td>
</tr>
<tr>
<td>Type B-tension band injuries</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>5</td>
</tr>
<tr>
<td>B2</td>
<td>6</td>
</tr>
<tr>
<td>B3</td>
<td>7</td>
</tr>
<tr>
<td>Type C-translation injuries</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>8</td>
</tr>
</tbody>
</table>
LSC: 7 (>60%, >2 mm apposition, little correction)
LSC: >6 for more than 1 up / 1 down

TABLE 1. McCormack Load-sharing Classification.

<table>
<thead>
<tr>
<th>Score</th>
<th>1 Point</th>
<th>2 Points</th>
<th>3 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comminution</td>
<td>30%</td>
<td>30-60%</td>
<td>&gt;60%</td>
</tr>
<tr>
<td>Apposition of fragments</td>
<td>1 mm</td>
<td>2 mm</td>
<td>&gt;2 mm</td>
</tr>
<tr>
<td>Deformity correction</td>
<td>3°</td>
<td>4°-9°</td>
<td>&gt;10°</td>
</tr>
</tbody>
</table>

PLAN: L3-S1 fusion, L4-5 laminectomy, L5/S1 TLIF
Case

- HPI: 46 M who was hanging a deer stand ~30 feet in the air when fell to ground. Severe LBP, unable to stand.
- CT: Severely comminuted L3 fracture with retropulsion
- EXAM:
  - Motor: 4+/5 bilateral IPs, otherwise 5/5 BLE
• AO Spine: 9
  • A4:B2: 6 points
  • N2: 2 points
  • M1: 1 points
  • >5: Operate

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A: compression fractures</td>
<td></td>
</tr>
<tr>
<td>A0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>1</td>
</tr>
<tr>
<td>A2</td>
<td>2</td>
</tr>
<tr>
<td>A3</td>
<td>3</td>
</tr>
<tr>
<td>A4</td>
<td>5</td>
</tr>
<tr>
<td>Type B: tension band injuries</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>5</td>
</tr>
<tr>
<td>B2</td>
<td>6</td>
</tr>
<tr>
<td>B3</td>
<td>7</td>
</tr>
<tr>
<td>Type C: translational injuries</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>8</td>
</tr>
</tbody>
</table>

**Case**

- TLICS: 7
  - Burst: 2
  - PLC: 3*
  - Neuro: 2
  - *No MRI

<table>
<thead>
<tr>
<th>TLICS</th>
<th>3 independent predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphology immediate stability</td>
<td>- Compression 1&lt;br&gt; - Burst 2&lt;br&gt; - Translation/rotation 3&lt;br&gt; - Distraction 4&lt;br&gt; - Radiographs 2&lt;br&gt; - CT 4</td>
</tr>
<tr>
<td>Integrity of PLC longterm stability</td>
<td>- Intact 0&lt;br&gt; - Suspected 2&lt;br&gt; - Injured 3&lt;br&gt; - MRI 2</td>
</tr>
<tr>
<td>Neurological status</td>
<td>- Intact 0&lt;br&gt; - Nerve root 2&lt;br&gt; - Complete cord 2&lt;br&gt; - Incomplete cord 3&lt;br&gt; - Cauda equina 3&lt;br&gt; - Physical examination 2</td>
</tr>
<tr>
<td>Predicts</td>
<td>Need for surgery 0–3&lt;br&gt; - nonsurgical surgeon’s choice 4&lt;br&gt; - surgical &gt;4</td>
</tr>
</tbody>
</table>
LSC: 7 (>60%, >2 mm apposition, little correction)
LSC: >6 for more than 1 up / 1 down

**TABLE 1. McCormack Load-sharing Classification.**

<table>
<thead>
<tr>
<th>Score</th>
<th>1 Point</th>
<th>2 Points</th>
<th>3 Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comminution</td>
<td>30%</td>
<td>30-60%</td>
<td>&gt;60%</td>
</tr>
<tr>
<td>Apposition of fragments</td>
<td>1 mm</td>
<td>2 mm</td>
<td>&gt;2 mm</td>
</tr>
<tr>
<td>Deformity correction</td>
<td>3°</td>
<td>4°-9°</td>
<td>&gt;10°</td>
</tr>
</tbody>
</table>

PLAN: L2-4 lami, L1-5 fusion, CSF leak repair
Case

- **HPI:** 32 F in an MVC, had BLE paresthesias and severe back pain.
- **CT:** unstable 3 column fracture of her T8 vertebrae with kyphotic angulation and coronal plane deformity; also has nondisplaced Jefferson fracture
- **MR:** cord compression with signal change
- **EXAM:**
  - 5/5 BLE with pain
  - Abnormal sensation below T8
  - Rectal tone normal, intact perineal sensation
• AO Spine: 13
  • C: 8 points
  • N3: 4 points (incomplete cord injury)
  • M1: 1 points
  • >5: Operate

Table 3: Point allocation for morphologic groups

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A—compression fractures</td>
<td></td>
</tr>
<tr>
<td>A0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>1</td>
</tr>
<tr>
<td>A2</td>
<td>2</td>
</tr>
<tr>
<td>A3</td>
<td>3</td>
</tr>
<tr>
<td>A4</td>
<td>5</td>
</tr>
<tr>
<td>Type B—tension band injuries</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>5</td>
</tr>
<tr>
<td>B2</td>
<td>6</td>
</tr>
<tr>
<td>B3</td>
<td>7</td>
</tr>
<tr>
<td>Type C—translation injuries</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>8</td>
</tr>
</tbody>
</table>
Case

- TLICS: 9
  - Translation/Rotation: 3
  - PLC: 3
  - Neuro: 3

TLICS 3 independent predictors

<table>
<thead>
<tr>
<th>Morphology immediate stability</th>
<th>Predicts Need for surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression</td>
<td>1</td>
</tr>
<tr>
<td>Burst</td>
<td>2</td>
</tr>
<tr>
<td>Translation/rotation</td>
<td>3</td>
</tr>
<tr>
<td>Distraction</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Integrity of PLC longterm stability</th>
<th>Predicts Need for surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact</td>
<td>0</td>
</tr>
<tr>
<td>Suspected</td>
<td>2</td>
</tr>
<tr>
<td>Injured</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Neurological status</th>
<th>Predicts Need for surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact Nerve root</td>
<td>0</td>
</tr>
<tr>
<td>Complete cord</td>
<td>2</td>
</tr>
<tr>
<td>Incomplete cord</td>
<td>3</td>
</tr>
<tr>
<td>Cauda equina</td>
<td>3</td>
</tr>
</tbody>
</table>

LSC: 8 (>60%, >2 mm apposition, 4-9° correction)
LSC: >6 for more than 1 up / 1 down

**TABLE 1. McCormack Load-sharing Classification.**

<table>
<thead>
<tr>
<th>Score</th>
<th>1 Point</th>
<th>2 Points</th>
<th>3 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comminution</td>
<td>30%</td>
<td>30-60%</td>
<td>&gt;60%</td>
</tr>
<tr>
<td>Apposition of fragments</td>
<td>1 mm</td>
<td>2 mm</td>
<td>&gt;2 mm</td>
</tr>
<tr>
<td>Deformity correction</td>
<td>3°</td>
<td>4°-9°</td>
<td>&gt;10°</td>
</tr>
</tbody>
</table>
Case

- HPI: 32 M rollover MVC. In ER found to have T10-11 fracture-dislocation with bilateral jumped facets.
- Exam: T10 ASIA A
• AO Spine: 13
  • C: 8 points
  • N4: 4 points (Complete cord injury)
  • M1: 1 points
  • >5: Operate

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A-compression fractures</td>
<td></td>
</tr>
<tr>
<td>A0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>1</td>
</tr>
<tr>
<td>A2</td>
<td>2</td>
</tr>
<tr>
<td>A3</td>
<td>3</td>
</tr>
<tr>
<td>A4</td>
<td>5</td>
</tr>
<tr>
<td>Type B-tension band injuries</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>5</td>
</tr>
<tr>
<td>B2</td>
<td>6</td>
</tr>
<tr>
<td>B3</td>
<td>7</td>
</tr>
<tr>
<td>Type C-translational injuries</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>8</td>
</tr>
</tbody>
</table>
Case

- TLICS: 8
  - Translation/Rotation: 3
  - PLC: 3*
  - Neuro: 2
  - *No MRI

TLICS: 3 independent predictors

<table>
<thead>
<tr>
<th>Morphology immediate stability</th>
<th>TLICS</th>
<th>Intact</th>
<th>Suspected</th>
<th>Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Burst</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Translation/rotation</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Distraction</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Radiation</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>CT</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Integrity of PLC longterm stability</th>
<th>TLICS</th>
<th>Intact</th>
<th>Nerve root</th>
<th>Complete cord</th>
<th>Incomplete cord</th>
<th>Cordae equina</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Suspected</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Injured</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Neurological status</th>
<th>TLICS</th>
<th>Intact</th>
<th>Nerve root</th>
<th>Complete cord</th>
<th>Incomplete cord</th>
<th>Cordae equina</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nerve root</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Complete cord</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Incomplete cord</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Cordae equina</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Predicts</th>
<th>Need for surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>non-surgical surgeon's choice</td>
</tr>
<tr>
<td>1</td>
<td>surgical</td>
</tr>
<tr>
<td>2</td>
<td>surgical</td>
</tr>
<tr>
<td>3</td>
<td>surgical</td>
</tr>
<tr>
<td>4</td>
<td>surgical</td>
</tr>
</tbody>
</table>

LSC: 5 (<30%, 1 mm apposition, >10° correction)
LSC: Doesn’t really apply here

Table 1. McCormack Load-sharing Classification.

<table>
<thead>
<tr>
<th>Score</th>
<th>1 Point</th>
<th>2 Points</th>
<th>3 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comminution</td>
<td>30%</td>
<td>30–60%</td>
<td>&gt;60%</td>
</tr>
<tr>
<td>Apposition of fragments</td>
<td>1 mm</td>
<td>2 mm</td>
<td>&gt;2 mm</td>
</tr>
<tr>
<td>Deformity correction</td>
<td>3°</td>
<td>4°–9°</td>
<td>&gt;10°</td>
</tr>
</tbody>
</table>
Plan: Open reduction of T10-11 dislocation, T9-12 fusion

Case

• HPI: 22 F, supermorbid obesity (BMI 74, 505 lbs), restrained driver in MVC vs tree.

• CT T11 fx

• EXAM:
  – E4, PERRL
  – O x 3
  – 5/5 BUE, >AG BLE (BLE casted)
Case:

- AO Spine: 13
  - C: 8 points
  - N3: 4 points (Incomplete cord injury?)
  - M1: 1 points
  - >5: Operate

Table 3: Point allocation for morphologic groups:

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A—Compression fractures</td>
<td></td>
</tr>
<tr>
<td>A0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>1</td>
</tr>
<tr>
<td>A2</td>
<td>3</td>
</tr>
<tr>
<td>A4</td>
<td>5</td>
</tr>
<tr>
<td>Type B—Tension band injuries</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>5</td>
</tr>
<tr>
<td>B2</td>
<td>6</td>
</tr>
<tr>
<td>B3</td>
<td>7</td>
</tr>
<tr>
<td>Type C—Translational injuries</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>8</td>
</tr>
</tbody>
</table>
Case

- TLICS: 10
  - Distraction: 4
  - PLC: 3*
  - Neuro: 3?
  - *No MRI

TLICS: 3 independent predictors

<table>
<thead>
<tr>
<th>TLICS</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Predicts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Morphology</td>
<td>Integrity of PLC</td>
<td>Neurological status</td>
<td>Need for surgery</td>
</tr>
<tr>
<td></td>
<td>immediate stability</td>
<td>longterm stability</td>
<td>status</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Compression</td>
<td>Intact</td>
<td>Intact</td>
<td>0 - 3</td>
</tr>
<tr>
<td></td>
<td>Burst</td>
<td>Suspected</td>
<td>Nerve root</td>
<td>- nonsurgical surgeon's choice</td>
</tr>
<tr>
<td></td>
<td>Translation/rotation</td>
<td>Injured</td>
<td>Complete cord</td>
<td>- surgical</td>
</tr>
<tr>
<td></td>
<td>Distraction</td>
<td></td>
<td>Incomplete cord</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 - 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- nonsurgical surgeon's choice</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- surgical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 - 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 - 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 - 3</td>
</tr>
</tbody>
</table>

LSC: 3 (<30%, 1 mm apposition, 3° correction)
LSC: Doesn’t really apply here

TABLE 1. McCormack Load-sharing Classification.

<table>
<thead>
<tr>
<th>Score</th>
<th>1 Point</th>
<th>2 Points</th>
<th>3 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comminution</td>
<td>&lt;30%</td>
<td>30-60%</td>
<td>&gt;60%</td>
</tr>
<tr>
<td>Apposition of fragments</td>
<td>1 mm</td>
<td>2 mm</td>
<td>&gt;2 mm</td>
</tr>
<tr>
<td>Deformity correction</td>
<td>3°</td>
<td>4°-9°</td>
<td>&gt;10°</td>
</tr>
</tbody>
</table>
PLAN: T10-11 decompression, T8-L1 fusion

Diffuse Idiopathic Skeletal Hyperostosis (DISH)
Case

- HPI: 83 M taken to ER after MVC. Initial trauma scans revealed right hemopneumothorax, and he was intubated and had 2 right sided chest tubes placed. Repeat scan (now intubated/sedated) demonstrated fishmouthing of T8-9 disc space.
- PMH: CAD on plavix, HTN, CKD, Afib on coumadin
- EXAM:
  - 4+/5 BLE
  - Sensation intact to LT BLE
• AO Spine: 13
  • C: 8 points
  • N3: 4 points (Incomplete cord injury?)
  • M1: 1 points
  • >5: Operate

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A - compression fractures</td>
<td></td>
</tr>
<tr>
<td>A0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>1</td>
</tr>
<tr>
<td>A2</td>
<td>2</td>
</tr>
<tr>
<td>A3</td>
<td>1</td>
</tr>
<tr>
<td>A4</td>
<td>5</td>
</tr>
<tr>
<td>Type B - tension band injuries</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>5</td>
</tr>
<tr>
<td>B2</td>
<td>6</td>
</tr>
<tr>
<td>B3</td>
<td>7</td>
</tr>
<tr>
<td>Type C - translational injuries</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>8</td>
</tr>
</tbody>
</table>

Case

• TUCS: 10
  - Distraction: 4
  - PLC: 3
  - Neuro: 3
  - *No MRI

<table>
<thead>
<tr>
<th>TLICS</th>
<th>3 independent predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphology immediate stability</td>
<td>Compression</td>
</tr>
<tr>
<td>Integrity of PLC long term stability</td>
<td>Intact</td>
</tr>
<tr>
<td>Neurological status</td>
<td>Intact</td>
</tr>
<tr>
<td>Predicts</td>
<td>Need for surgery</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Predicts</th>
<th>Need for surgery</th>
<th>0–4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicts</td>
<td>Need for surgery</td>
<td>&gt;4</td>
</tr>
</tbody>
</table>
LSC: 5 (<30%, 1 mm apposition, >10° correction)
LSC: Doesn’t really apply here

TABLE 1. McCormack Load-sharing Classification.

<table>
<thead>
<tr>
<th>Score</th>
<th>1 Point</th>
<th>2 Points</th>
<th>3 Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communion</td>
<td>30%</td>
<td>30–60%</td>
<td>&gt;60%</td>
</tr>
<tr>
<td>Apposition of fragments</td>
<td>1 mm</td>
<td>2 mm</td>
<td>&gt;2 mm</td>
</tr>
<tr>
<td>Deformity correction</td>
<td>3°</td>
<td>4°–9°</td>
<td>&gt;10°</td>
</tr>
</tbody>
</table>

PLAN: T8/9 laminectomy, T6-11 fusion
ANKYLOSING SPONDYLITIS

Case

- HPI: 74 M was walking to mailbox when dog tripped him, he fell, had excruciating back pain.
- Taken to OSH, CT revealed T11-12 fracture dislocation is setting of AS
- 5/5 BLE
• AO Spine: 9
  • C: 8 points
  • N0: 0 points
  • M1: 1 points
  • >5: Operate

Table 3: Point allocation for morphologic groups

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A—compression fractures</td>
<td></td>
</tr>
<tr>
<td>A0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>1</td>
</tr>
<tr>
<td>A2</td>
<td>2</td>
</tr>
<tr>
<td>A3</td>
<td>3</td>
</tr>
<tr>
<td>A4</td>
<td>5</td>
</tr>
<tr>
<td>Type B—tension band injuries</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>5</td>
</tr>
<tr>
<td>B2</td>
<td>6</td>
</tr>
<tr>
<td>B3</td>
<td>7</td>
</tr>
<tr>
<td>Type C—translational injuries</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>8</td>
</tr>
</tbody>
</table>
Case

- TLICS: 7
  - Distraction: 4
  - PLC: 3
  - Neuro: 0

LSC: 5 (<30%, 1 mm apposition, >10° correction)
LSC: Doesn’t really apply here

```
<table>
<thead>
<tr>
<th>TLICS</th>
<th>3 independent predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Morphology immediate stability</td>
</tr>
<tr>
<td></td>
<td>- Compression</td>
</tr>
<tr>
<td></td>
<td>- Burst</td>
</tr>
<tr>
<td></td>
<td>- Translation/rotation</td>
</tr>
<tr>
<td></td>
<td>- Distraction</td>
</tr>
<tr>
<td>2</td>
<td>Integrity of PLC longterm stability</td>
</tr>
<tr>
<td></td>
<td>- Intact</td>
</tr>
<tr>
<td></td>
<td>- Suspected</td>
</tr>
<tr>
<td></td>
<td>- Injured</td>
</tr>
<tr>
<td>3</td>
<td>Neurological status</td>
</tr>
<tr>
<td></td>
<td>- Intact Nerve root</td>
</tr>
<tr>
<td></td>
<td>- Complete cord</td>
</tr>
<tr>
<td></td>
<td>- Incomplete cord</td>
</tr>
<tr>
<td></td>
<td>- Caudal equina</td>
</tr>
<tr>
<td>Predicts</td>
<td>Need for surgery</td>
</tr>
<tr>
<td></td>
<td>0 – 3</td>
</tr>
</tbody>
</table>

TABLE 1. McCormack Load-sharing Classification.

<table>
<thead>
<tr>
<th>Score</th>
<th>1 Point</th>
<th>2 Points</th>
<th>3 Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comminution</td>
<td>30%</td>
<td>30–60%</td>
<td>&gt;60%</td>
</tr>
<tr>
<td>Apposition of fragments</td>
<td>1 mm</td>
<td>2 mm</td>
<td>&gt;2 mm</td>
</tr>
<tr>
<td>Deformity correction</td>
<td>3°</td>
<td>4°–9°</td>
<td>&gt;10°</td>
</tr>
</tbody>
</table>
PLAN: T12 lami, T9-L3 fusion

Questions?
Evaluation and treatment of cervical deformities

Ricardo Fontes, MD, PhD
Department of Neurosurgery, RUMC

Disclosures

• Consulting work
  – Globus

Not applicable to this topic or presentation
Objectives

• Revise principles of alignment and evaluation of cervical deformity

• Explain technical aspects of multilevel discectomy, anterior and posterior osteotomies

• Provide case examples of subaxial cervical and cervicothoracic deformities

Introduction – Cervical Spine Deformity

• Ranges from minimal to severely symptomatic

• Focal
• Regional
• Global

• Most common: minimally symptomatic subaxial kyphosis
  – Myelopathy
  – Radiculopathy
Introduction – Cervical Spine Deformity

- Ranges from minimal to severely symptomatic

- Failure to maintain horizontal gaze: more restrictive than lower thoracic paraplegia
Introduction – Cervical Spine Deformity

- Neurological
- Dysphagia
- Vision
- Cosmetic
- Pain

Evaluation and assessment

- Complete HPI
- Physical exam
  - Neurological
  - Musculoskeletal including alignment
    - Trapezius sign
    - Lumbar compensation
    - Horizontal gaze
  - Assessment of flexibility of deformity
- Cervical flexion/neutral/extension radiographs
- Full-length scoliosis films
Evaluation and assessment

- Complete HPI
- Physical exam
  - Neurological
  - Musculoskeletal including alignment
  - Assessment of flexibility of deformity
  - Horizontal gaze
- Cervical flexion/neutral/extension radiographs
- Full-length scoliosis films

Evaluation and assessment

- Understand the deformity:
  - Localize
  - Cause
    - Degenerative
    - Iatrogenic
    - Rheumatological
    - Neoplastic / Post-radiation
    - Traumatic
  - Describe
  - Is it a problem?
  - Will it become a problem after I fuse the spine?
Evaluation and assessment

Describing the deformity

- Cervical alignment
  - C2-7 / C1-7 lordosis
  - C2-7 SVA
  - T1 slope
- Global alignment
- Flexible / rigid
- Management
  - O-C2
  - C2-C7
  - T1 and below

Evaluation and assessment

- Ames-ISSG classification

<table>
<thead>
<tr>
<th>Deformity Descriptor</th>
<th>5 Modifiers</th>
</tr>
</thead>
<tbody>
<tr>
<td>C: Primary Sagittal Deformity Apex in Cervical Spine</td>
<td>C2-C7 sagittal vertical axis (SVA)</td>
</tr>
<tr>
<td>CT: Primary Sagittal Deformity Apex at Cervico-Thoracic Junction</td>
<td>+ C2-C7 TIA &lt; 4 cm</td>
</tr>
<tr>
<td>T: Primary Sagittal Deformity Apex in Thoracic Spine</td>
<td>+ C2-C7 TIA &lt; 4 cm</td>
</tr>
<tr>
<td>S: Primary Coronal Deformity (C2-C7 Cobb angle &gt; 15°)</td>
<td>+ C2-C7 TIA &gt; 8 cm</td>
</tr>
<tr>
<td>OT: Primary Cranio-Vertebral Junction Deformity</td>
<td></td>
</tr>
</tbody>
</table>
Treatment of cervical deformity

• Is it a problem?
• Will it become a spine after the spine is fused?

Treatment algorithm C2-C7

Attention:
• Elevated T1 slope
  • Thoracic kyphosis – T1/T2 PSO, lumbar correction
• Ankylosing spondylitis
  • Posterior only 3CO – C7 Smith-Petersen, T1/T2 PSO
Subaxial cervical deformity

- Subaxial deformity
- **Posterior fusion?**
  - Open: Cervical 360 (A-P)
  - Fused: Cervical 540 (P-A-P)

- Principle: reconstruction of the anterior column
  - May be complemented by posterior osteotomies and correction maneuvers

Ames et al (2013)
Case 1

- 81yoF with neck pain and failure to maintain horizontal gaze

![Image showing cervical spine X-ray]

- C2-7 SVA 85mm
- C2-7 kyphosis 54deg
- T1 slope 25deg

Treatment algorithm C2-C7

Cervical kyphotic deformity

- Non-fixed / "flexible"
- Fixed

  - Mild / sick / elderly or very flexible

  - Posterior only (rare)

  - MRI
    - Anti-Posterior Instability
    - Anti-Posterior Instability

  - T1 slope

  - Posterior fusion?

  - +
    - Anti-Posterior Instability
    - Anti-Posterior Instability

  - -

Attention:
- Elevated T1 slope
  - Thoracic kyphosis – T1/T2 PSO, lumbar correction
- Ankylosing spondylitis
  - Posterior only 3CO – C7 Smith-Petersen, T1 PSO
Case 1

- 81yoF with neck pain and failure to maintain horizontal gaze

![Rear view of the cervical spine with an x-ray showing a posterior fusion at C2-C5 level.]

Case 2

- 36yoM, MVA with C3 facet fracture and central cord syndrome
  - 3 months s/p C2-C5 posterior fusion

<table>
<thead>
<tr>
<th>Measure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2-7 SVA</td>
<td>12mm</td>
</tr>
<tr>
<td>C2-7 kyphosis</td>
<td>25deg</td>
</tr>
<tr>
<td>T1 slope</td>
<td>2deg</td>
</tr>
</tbody>
</table>
Treatment algorithm C2-C7

Cervical kyphotic deformity

- Non-fixed / “flexible”
  - Mild / sick / elderly or very flexible
  - Posterior only (rare)
- Fixed
  - Posterior fusion?
    - +

Attention:
- Elevated T1 slope
  - Thoracic kyphosis – T1/T2 PSO, lumbar correction
- Ankylosing spondylitis
  - Posterior only 3CO – C7 Smith-Petersen, T1 PSO

Case 2

- 36yoM, MVA with C3 facet fracture and central cord syndrome
  - 3 months s/p C2-C5 posterior fusion – cervical S40
Surgical Technique and Tricks

- Setup
- Special intubation techniques
- Neuromonitoring
- Special equipment
  - Jackson frame
  - Traction
  - Headholder
  - Thompson retractor
  - Implants
- Osteotomies
- Correction techniques
- Postoperative support
Surgical Technique and Tricks

• Setup
• Special intubation techniques
• Neuromonitoring
• Special equipment
  – Jackson frame
  – Traction
  – Headholder
  – Thompson retractor
  – Implants
• Osteotomies
• Correction techniques
• Postoperative support
Surgical Technique and Tricks

- Setup
- Special intubation techniques
- Neuromonitoring
- Special equipment
  - Jackson frame
  - Traction
  - Headholder
  - Thompson retractor
  - Implants
- Osteotomies
- Correction techniques
- Postoperative support

Ames et al (2013)

Elevated T1 slope – CT / TL deformity

- Special tricks and tips
  - Frequently postoperative deformity
  - Correct TL lumbar first
  - Upper thoracic 3COs
    - PSO vs VCR
    - C7 vs T1 vs T2 vs other
Case 3

- 62yoM with inability to maintain horizontal gaze
Case 3

- 62yoM with inability to maintain horizontal gaze

Case 3

- 62yoM with inability to maintain horizontal gaze – T2 VCR
Case 4

- 60yoF with neck pain, low back pain, inability to maintain horizontal gaze, myelopathy

![Images of medical scans]
Case 4

- 60yoF with neck pain, low back pain, inability to maintain horizontal gaze, myelopathy – T4-P, L4 PSO
Case 4

- 60yoF with neck pain, low back pain, inability to maintain horizontal gaze, myelopathy – T4-P, L4 PSO, T4 PSO

Ankylosing spondylitis – Case 5

- 60yoM with 35-year AS, global kyphosis
Surgical Technique and Tricks

Ankylosing spondylitis – Case 5

- 60yoM with 35-year AS, global kyphosis
Ankylosing spondylitis – Case 5

• 60yoM with 35-year AS, global kyphosis
Ankylosing spondylitis – Case 5

- 60yoM with 35-year AS, global kyphosis

Postoperative Care and Complications

- Postoperative support / complications
  - Cuff leak test
    - Audible
    - Value - ~200mL? 120mL?
  - Fontes et al., 2020 – Cervical 360 /540
    - 15% tracheostomy, 20% gastrostomy
    - Larger preoperative leak – protected (p=0.053)
    - Worse prognosis – shorter patients, infraglottic luminal area
    - All patients decannulated and on fully oral diet by 7 weeks
  - Kim HJ et al., 2022
    - 18.9% neurological complication rate
    - 54.5% non-neurological complication rate

- DJK
  - 25-30% radiological
  - 6-10% symptomatic requiring revision

Passias et al., 2018
Passias et al., 2021
Conclusions

• Not every cervical deformity needs treatment
• Very successful results with elevated patient satisfaction
• Specialized techniques and postoperative care are necessary
• Patient / team aware of risks and complications
• Institutional support
• Next steps:
  – Dissemination
  – 3COs for primary degenerative cases with myelopathy
  – AI and improved patient/technique selection

Thank you!
ricardo_fontes@rush.edu
+1-224-531-2153
Contemporary Management of Odontoid Fractures

Vincent C. Tzvetanov
Department of Neurosurgery
Rush University Medical Center

Disclosures

- Fellowship Support
  - NREF
- Consultant
  - Medtronic
  - NeVasive
- Royalties
  - Medtronic

ODONTOID FRACTURES

- 10-18% of all cervical fxs
- 60% of all C2 fxs
  - Mostly A/A Type II
  - Occipital
- Neuro deficit 18-26%
- Most patients are older
  - >30% patients over age 80

Denise

- Independently living 91 year old woman tripped on carpet 12/25/2018 and fell. Fall witnessed by her son
- No LOC or neurological symptoms
- Evaluated in ETC with CT Scan and found to have a Type 2 odontoid fracture
- Hypertension, cataract surgery
- Hgb 11.2
- Normal neurological exam
Type II Odontoid Fractures

- **No Treatment**
  - 18 patients - 100% nonunion
Type II Odontoid Fractures

- Halo
  - 0 - 79% success
  - Patients > 50 years 21 times more likely to fail halo than those less than 50.

Halo Vest Immobilization in the Elderly: A Death Sentence?

- OLD vs. YNG
  - OLD n=129, mean age 79 years
  - YNG n=239, mean age 38 years
  - Exclusion - death within 24 hours
  - Injury severity score significantly higher in YNG (18.9 vs. 14.8)
  - Mortality 21% OLD vs. 5% YNG

Table II. Complication Rates for Halo Vest Immobilization (HVI) and Non-HVI

<table>
<thead>
<tr>
<th>Complication</th>
<th>HVI (N=129)</th>
<th>Non-HVI (N=239)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneumonia</td>
<td>10 (7.8%)</td>
<td>3 (1.2%)</td>
<td>.003</td>
</tr>
<tr>
<td>Cardiac arrest</td>
<td>10 (2.8%)</td>
<td>2 (0.8%)</td>
<td>.01</td>
</tr>
<tr>
<td>Deep venous thrombosis/pulmonary embolism</td>
<td>2 (5.5%)</td>
<td>1 (0.4%)</td>
<td>.46</td>
</tr>
<tr>
<td>Urinary tract infection</td>
<td>9 (7.8%)</td>
<td>3 (1.2%)</td>
<td>.02</td>
</tr>
<tr>
<td>Overall</td>
<td>26 (20.6%)</td>
<td>15 (6.3%)</td>
<td>.01</td>
</tr>
</tbody>
</table>

Type II Odontoid Fractures

- Collar
  - 4 – 6 weeks traction then rigid orthosis
  - 64 – 73% successful fusion
Smith et al Spine 2013
- AO Geriatric Fracture Study
- 58 patients treated nonoperatively
  - 8 died in 90 days so 50 studied
  - 30% (15) nonunion, 20% (11) operated
  - NDI and SF36 not significantly different at 1 year between union and nonunion
  - Many nonunions had surgery

Fehlings et al Spine 2013
- AO Jamboree
- 159 patients > 65 years
  - 101 surgical, 58 nonsurgical
  - Define treatment failure
  - Death, occurrence of a major complication, decline in NDI by more than 9.5 points
  - Association with failure
    - Older age OR 1.08 for each year
    - Initial nonsurgical OR 3.08
    - Male sex OR 4.35
    - Baseline neurological status OR 4.13

Nonoperative management associated with higher mortality
Robinson A-L, Olenud C, Robinson V. Spine J 2018
Fen L, Ou D, Huang X, et al. Medscape 2019

- National Inpatient Sample (NIS) Age 65 – 90; 2003 – 2017
- 32,419 patients
  - Mean age 77 years
  - 54% female
  - Operative treatment
    - 2003 46%  
    - 2017 86%
  - Inpatient mortality
    - Operative 3.6%
    - Non-operative 5.9%
Type II Odontoid Fractures

- No Treatment
- Halo
- Collar
- Anterior Screw Fixation
  - Posterior Fusion
    - Brooks
    - Screw fixation
      - Transarticular
      - C1 - C2 pars/pedicle
      - C1 - C2 laminar

ODONTOID SCREW FIXATION

- Bohler, Nakanishi
  - 1982
- Spares cervical rotation
- No bone graft
- No halo immobilization

ODONTOID SCREW

- Odontoid screw is as stable as C1-2 wiring in torsion and more stable in bending
  - Graziano, Spine 1993
- No significant difference between one and two screw techniques under loading to failure
- Single screw = 50% of unfractured odontoid
  - Sasso, Spine 1993
- 10% of odontoid fxs have ruptured TAL
  - Greene, Spine 1994

Anterior Fixation of Odontoid Fractures in the Elderly

- 57 patients overall
- 42 patients >70; mean 15 month f/u
  - Fusion 57%
  - Stable fibrous union 24%
  - Nonunion 19%
- Single screw
  - 56% stability
- Two screws
  - 96% stability
Anterior Screw Fixation

- “We conclude that anterior screw fixation according to Bolser is associated with an unacceptably high rate of problems in the elderly. Probable causes may be osteoporosis with comminution at the fracture site, or stiffness of the cervical spine preventing ideal positioning of the screws. As non-operative treatment also often fails, the method of choice seems to be posterior C1-C2 fusion.”

Posterior Fixation

- Brooks Fusion 35 – 92% success
- Transosseous nail

- Transarticular Fixation
- C12 Fixation
- Pars, pedicle, laminar

Nottingham Hip Fracture Score predicts 30 day mortality in patients with a hip fracture

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Score</th>
<th>Total</th>
<th>30 day Mortality Hip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>&gt;86</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td>Male</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Admit Hgb</td>
<td>&lt;10g/dl</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>MMTS</td>
<td>&lt;6/10</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Living in Institution</td>
<td>Yes</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Comorbidities</td>
<td>&gt;2</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Malignancy</td>
<td>Yes</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>4</td>
<td>6.2%</td>
<td></td>
</tr>
</tbody>
</table>

Denise

Shafay et al. Predictors of mortality in the elderly patients with a fracture of the odontoid process. *Bone Joint J* 2019
Odontoid Fractures VCT Experience

- 93 consecutive patients over the age of 65
  - 47 women, 46 men
  - Mean age 78 years (65-95 years)
  - Mean hospitalization 9.6 days (2 - 37)
  - Mean follow-up 14 months
- Cause of injury in all but 8 was a fall from a standing height
- Neurological Status
  - 3 severe spinal cord injury
  - 7 cervical myelopathy
- 37 patients had additional fractures

MORTALITY

<table>
<thead>
<tr>
<th>Age (years)/gender</th>
<th>Comorbidities</th>
<th>Other injuries</th>
<th>Complications</th>
<th>Cause of death</th>
<th>Hospitalization (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>89/f</td>
<td>Renal insufficiency CHF</td>
<td>Humerus fracture ARDS</td>
<td>Pulmonary edema</td>
<td>Sepsis</td>
<td>19</td>
</tr>
<tr>
<td>83/m</td>
<td>COPD CHF CAD</td>
<td>Metacarpal fractures</td>
<td>Sepsis, renal failure</td>
<td>Sepsis</td>
<td>5</td>
</tr>
<tr>
<td>84/f</td>
<td>HTN Asthma</td>
<td>None</td>
<td>Pneumonia, sepsis</td>
<td>Sepsis</td>
<td>9</td>
</tr>
</tbody>
</table>

COMORBIDITIES

<table>
<thead>
<tr>
<th>NUMBER OF PATIENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypertension (HTN) 50</td>
</tr>
<tr>
<td>Coronary Artery Disease (CAD) 20</td>
</tr>
<tr>
<td>Diabetes 17</td>
</tr>
<tr>
<td>Atrial Fibrillation 14</td>
</tr>
<tr>
<td>Cancer 7</td>
</tr>
<tr>
<td>Hypercholesterolemia/Hyperlipidemia 7</td>
</tr>
<tr>
<td>Renal Insufficiency 6</td>
</tr>
<tr>
<td>Congestive Heart Failure (CHF) 6</td>
</tr>
<tr>
<td>Asthma 6</td>
</tr>
<tr>
<td>Chronic Obstructive Pulmonary disease (COPD) 6</td>
</tr>
<tr>
<td>Dementia 6</td>
</tr>
<tr>
<td>Pacemaker 3</td>
</tr>
<tr>
<td>Parkinson Disease 3</td>
</tr>
<tr>
<td>Thyroid Disease 3</td>
</tr>
<tr>
<td>Alcohol Abuse 3</td>
</tr>
<tr>
<td>Rheumatoid Arthritis 2</td>
</tr>
<tr>
<td>Stroke 2</td>
</tr>
<tr>
<td>History of DVT 2</td>
</tr>
<tr>
<td>Epilepsy 1</td>
</tr>
</tbody>
</table>

COMPLICATIONS

<table>
<thead>
<tr>
<th># PATIENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death 3 (3.22%)</td>
</tr>
<tr>
<td>Pneumonia 8</td>
</tr>
<tr>
<td>Wound infection 2</td>
</tr>
<tr>
<td>Urinary tract infection 2</td>
</tr>
<tr>
<td>Hyponatremia 2</td>
</tr>
<tr>
<td>Acute Respiratory Distress Syndrome 1</td>
</tr>
<tr>
<td>Medication rash 1</td>
</tr>
<tr>
<td>Myocardial infection 1</td>
</tr>
<tr>
<td>Pulmonary embolism 1</td>
</tr>
<tr>
<td>Renal failure 1</td>
</tr>
<tr>
<td>Sepsis 2</td>
</tr>
</tbody>
</table>
Fixation

- Bilateral C12 transarticular screws: 20
- Unilateral C12 transarticular screws: 3
- Unilateral C12, contralateral C1 pars/lamina: 5
- Bilateral C1 - C2 pars interarticularis: 44
- Bilateral C1 - C2 lamina: 14
- C1-Pars with contralateral lamina: 2
- Complex fusion (occiput or subaxial with C12): 5

Transarticular Screw Fixation

- 98% fusion

- 96% fusion

C1C2 Transarticular Screw Fixation

- Limited by anatomy
  - Proper reduction
  - Vertebral artery
  - Thoracic kyphosis

Atlantoaxial Fixation Complications

- Hypoglossal nerve
- C1 lateral mass
- C1-C2 facet joint
C1-C2 Screw Fixation

- 100% fusion
- no neural or vascular injuries

Goel et al. 1994

Harms, Melcher Spine 2001

---

### Atlantoaxial Fusions

**Relative Resistance to Loading**

- Grob et al. Spine 17:480-490, 1992
- Hajek et al. Spine 18:173-177, 1993

---

### Atlantoaxial Fusions

**Relative Resistance to Loading**

<table>
<thead>
<tr>
<th></th>
<th>Gallie</th>
<th>Brooks</th>
<th>Clarmor</th>
<th>Screw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flex/extension</td>
<td>++</td>
<td>++++</td>
<td>++++</td>
<td>+++</td>
</tr>
<tr>
<td>AP translation</td>
<td>++</td>
<td>+++</td>
<td>++++</td>
<td>+++</td>
</tr>
<tr>
<td>Axial Rotation</td>
<td>+</td>
<td>+++</td>
<td>+++</td>
<td>++++</td>
</tr>
</tbody>
</table>
### Fusion Success

<table>
<thead>
<tr>
<th>Fixation</th>
<th>Total</th>
<th>Nonunion</th>
<th>% Fusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transarticular</td>
<td>17</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Atlas/C2 pars</td>
<td>29</td>
<td>1</td>
<td>97</td>
</tr>
<tr>
<td>Atlas/C2 lamina</td>
<td>9</td>
<td>3</td>
<td>67</td>
</tr>
<tr>
<td>Other*</td>
<td>9</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>
Clinical Studies

Modification of Wright's technique for placement of bilateral crossing C2 translaminar screws: technical note

Andrew Lee, MD, Rohit N. Sheth, MD, Steve Vanni, DO, Barth A. Green, MD, Allan D. Levi, MD, PhD

- 5303 patients > 60 years
- 92 odontoid fractures
- Quantitative CT
- Multivariate logistic regression model
- Decreased cMD is the major predisposing factor for odontoid fracture
  - OR = 3.666, 95% confidence
- Odontoid cysts
  - OR = 1.383; 95% confidence
Over 90% of patients will heal the fracture with posterior fixation.

Odontoid Fracture Healing with Posterior Fixation in Geriatric Patients

- 33%
- 73%
  - Tanyno J Neuromag. Spine 2021
74 year old man
- Wore a hand brace while mountain biking
- Orthosis recommended
  - Wore a neck collar for 5 months
- Fracture did not heal
- Constant neck pain exacerbated by any motion
  - Physical therapy was of no benefit
- Very active
  - Cross-country skiing
  - Downhill skiing
  - Kayaking
  - Cycling
Geriatric Odontoid Fractures

- Posterior fusion morbidity and mortality is acceptable
- Dysphagia and nonunion rates much less than with anterior procedure
- C1 - C2 transarticular technique only if no other option
- Consider temporary fixation
Predictive Analytics and ML for Process Improvement in Adult Deformity Surgery

Christopher P Ames MD
Professor of Neurosurgery and Orthopaedic Surgery
Director of Spinal Deformity and Spinal Tumor Surgery
University of California San Francisco

Cabo 2022
COI/Disclosures

- **Chris Ames, MD** has financial interests to disclose.
- Royalty: Depuy Synthes,
  
  Stryker, Medtronic, Nuvasive, Astura
- Consulting: Medtronic, Depuy Synthes, K2M, Medicrea, Agada Medical, Nuvasive, Carlsmed
- Research: Titan Spine, Depuy Synthes ISSG
- **Advisory Board Carlsmed**
- Editorial Board: Operative Neurosurgery, Neurospine
- Grant Funding: SRS, Medtronic, Truage
- Executive Committee ISSG
- Director Predictive Analytics ISSG
- Chair Safety And Value Committee SRS 2021
- Chair WWC SRS 2022
Spinal Surgery Analyzed as a Manufacturing Process?

Dear Dr. Ames,

Thank you for giving me my life back again. You are God's factory on earth and I shall never forget you and what you did.

With gratitude, love and light,

[Signature]

4/14/22

Types of Errors in Manufacturing Processes

- Processing errors
- Setup errors
- Missing parts
- Improper parts
- Operations errors
- Measurement errors

LOOP ANALYSIS PROCESS?
Six Sigma of Adult Deformity Failure

Lean Six Sigma

DMAIC

D
Define
Define the problem.

M
Measure
Quantify the problem.

A
Analyze
Identify the cause of the problem.

I
Improve
Implement and verify the solution.

C
Control
Maintain the solution.
"ASD Epidemic"

60% prevalence of scoliosis
>10 degrees over 65

Number of USA ASD Procedures increased by 157% in 10 years

Healthcare Costs and Utilization Project (HCUP http://hcupnet.ahrq.gov),

N of discharges with at least one diagnosis of spinal curvature
(ICD-9 code 737.0 to 737.9)
Competition for Healthcare Dollars

- Dementia – estimates of >1 trillion dollar US cost
- Cardiovascular
- Musculoskeletal

Third of Hongkongers over 80 will have dementia by 2050 as experts warn city is completely unprepared. Nobody likes dealing with aging. Especially Hong Kong.
NEED For INNOVATION

Categories of failure

- Mechanical failure
  - 1. Proximal Junctional Kyphosis
  - 2. Rod Fracture
  - 3. Pseudoarthrosis

- Clinical failure
  - 1. Pre-operative risk factors
  - 2. Post-operative risk factors

- Re-operation
  - 1. Radiographic failure
  - 2. Non-radiographic failure
    - Infection
    - Neurological symptoms
    - Other causes

- Cost ineffective
  - 1. Patient costs
  - 2. Hospital costs
  - 3. Societal Costs

Define
Define the problem.
Rod Fracture Rates

- Rod fracture rates range from 9-54% across studies.

- Several strategies to decrease rod fracture rates, most notably the use of additional rods

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Journal</th>
<th>Type</th>
<th>N</th>
<th>f/u (months)</th>
<th>RF rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Smith</td>
<td>Ngay</td>
<td>RO</td>
<td>442</td>
<td>12</td>
<td>6.8%</td>
</tr>
<tr>
<td>2014</td>
<td>Smith</td>
<td>JNSS</td>
<td>PO</td>
<td>200</td>
<td>24</td>
<td>9.0%</td>
</tr>
<tr>
<td>2015</td>
<td>Barton</td>
<td>Scoliosis</td>
<td>RO</td>
<td>75</td>
<td>12</td>
<td>9.3%</td>
</tr>
<tr>
<td>2017</td>
<td>Hamilton</td>
<td>World Ngy</td>
<td>RRPD</td>
<td>343</td>
<td>37.8</td>
<td>14.9%</td>
</tr>
<tr>
<td>2018</td>
<td>Yamato</td>
<td>JNSS</td>
<td>RRPD</td>
<td>304</td>
<td>12</td>
<td>18.0%</td>
</tr>
<tr>
<td>2018</td>
<td>Lertudomphonwanit</td>
<td>Spine</td>
<td>RO</td>
<td>526</td>
<td>24</td>
<td>18.4%</td>
</tr>
<tr>
<td>2018</td>
<td>Ailon</td>
<td>World Ngy</td>
<td>RRPD</td>
<td>205</td>
<td>24</td>
<td>17.1%</td>
</tr>
<tr>
<td>2018</td>
<td>Gupta</td>
<td>Op Ngy</td>
<td>RO</td>
<td>49</td>
<td>24</td>
<td>10.2%</td>
</tr>
<tr>
<td>2019</td>
<td>Jung</td>
<td>JNSS</td>
<td>RO</td>
<td>76</td>
<td>12</td>
<td>11.8%</td>
</tr>
<tr>
<td>2019</td>
<td>Zhao</td>
<td>Spine</td>
<td>RO</td>
<td>123</td>
<td>24</td>
<td>8.9%</td>
</tr>
<tr>
<td>2019</td>
<td>Adogwa</td>
<td>JNSS</td>
<td>RO</td>
<td>198</td>
<td>24</td>
<td>19.2%</td>
</tr>
<tr>
<td>2020</td>
<td>Lertudomphonwanit</td>
<td>The Spine J</td>
<td>RO</td>
<td>526</td>
<td>12</td>
<td>18.3%</td>
</tr>
<tr>
<td>2020</td>
<td>Yamato</td>
<td>Spine Deform</td>
<td>RRPD</td>
<td>48</td>
<td>24</td>
<td>54.2%</td>
</tr>
<tr>
<td>2021</td>
<td>Lee</td>
<td>JNSS</td>
<td>RO</td>
<td>178</td>
<td>24</td>
<td>26.0%</td>
</tr>
</tbody>
</table>
160 patients were included, 93 RFs occurred in 62 (38.8%) patients (41 unilateral, 21 bilateral)

*ASLS Data SRS 2022 submitted
PJK rates

- Aggregating data across studies highlights trends in failure rates across time and institution.
- For PJK: consistent across time, but newer technology has been shown to be promising.
- 9-41%

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Journal</th>
<th>Type</th>
<th>N</th>
<th>f/u (months)</th>
<th>PJK rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1062006</td>
<td>Dewald</td>
<td>Spine</td>
<td>RO</td>
<td>38</td>
<td>60</td>
<td>26.0%</td>
</tr>
<tr>
<td>1052008</td>
<td>Kim</td>
<td>Spine</td>
<td>RO</td>
<td>161</td>
<td>60</td>
<td>36.0%</td>
</tr>
<tr>
<td>1102013</td>
<td>Maruo</td>
<td>Spine</td>
<td>RO</td>
<td>90</td>
<td>24</td>
<td>40.0%</td>
</tr>
<tr>
<td>1112013</td>
<td>Bridwell</td>
<td>Nagy</td>
<td>RO</td>
<td>90</td>
<td>24</td>
<td>21.0%</td>
</tr>
<tr>
<td>1192013</td>
<td>Hassanzadeh</td>
<td>Spine Deform</td>
<td>RO</td>
<td>47</td>
<td>24</td>
<td>16.0%</td>
</tr>
<tr>
<td>1152013</td>
<td>Ha</td>
<td>Spine</td>
<td>RO</td>
<td>89</td>
<td>24</td>
<td>32.6%</td>
</tr>
<tr>
<td>1072014</td>
<td>Annis</td>
<td>EBCSJ</td>
<td>RO</td>
<td>135</td>
<td>24</td>
<td>38.5%</td>
</tr>
<tr>
<td>1042016</td>
<td>Liu</td>
<td>Eur Spine J</td>
<td>Meta</td>
<td>2215</td>
<td>24</td>
<td>30.0%</td>
</tr>
<tr>
<td>1132017</td>
<td>Han</td>
<td>Spine</td>
<td>RO</td>
<td>100</td>
<td>24</td>
<td>32.0%</td>
</tr>
<tr>
<td>1192017</td>
<td>Nicholls</td>
<td>Spine</td>
<td>RO</td>
<td>440</td>
<td>34</td>
<td>36.0%</td>
</tr>
<tr>
<td>1112017</td>
<td>Lafage</td>
<td>Spine</td>
<td>RO</td>
<td>679</td>
<td>24</td>
<td>45.1%</td>
</tr>
<tr>
<td>1022017</td>
<td>Luo</td>
<td>World Nagy</td>
<td>Meta</td>
<td>1230</td>
<td>24</td>
<td>32.2%</td>
</tr>
<tr>
<td>1132020</td>
<td>Yoshida</td>
<td>Spine</td>
<td>PO</td>
<td>113</td>
<td>12</td>
<td>8.9%</td>
</tr>
<tr>
<td>1122020</td>
<td>Line</td>
<td>Spine</td>
<td>RO</td>
<td>625</td>
<td>12</td>
<td>13.9%</td>
</tr>
<tr>
<td>1092021</td>
<td>Lafage</td>
<td>Spine Deform</td>
<td>RO</td>
<td>409</td>
<td>24</td>
<td>37.9%</td>
</tr>
</tbody>
</table>
Reoperation Rates

Re-operation rates range from

Overall revision surgery rate ranges from 7.6-30% (average of 20.2%)

How does this rate compare to other major surgery?

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Journal</th>
<th>Type</th>
<th>N</th>
<th>f/u (months)</th>
<th>Revision rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>Mok</td>
<td>Spine</td>
<td>RO</td>
<td>89</td>
<td>24</td>
<td>25.8%</td>
</tr>
<tr>
<td>2010</td>
<td>Pichelmann</td>
<td>Spine</td>
<td>RO</td>
<td>643</td>
<td>56.4</td>
<td>11.3%</td>
</tr>
<tr>
<td>2013</td>
<td>Scheer</td>
<td>JNSS</td>
<td>RO</td>
<td>352</td>
<td>24</td>
<td>17.0%</td>
</tr>
<tr>
<td>2014</td>
<td>Zhu</td>
<td>Spine</td>
<td>RO</td>
<td>815</td>
<td>36</td>
<td>7.6%</td>
</tr>
<tr>
<td>2014</td>
<td>Smith</td>
<td>JNSS</td>
<td>PO</td>
<td>346</td>
<td>24</td>
<td>28.2%</td>
</tr>
<tr>
<td>2016</td>
<td>Scheer</td>
<td>Eur. Spine J.</td>
<td>RO</td>
<td>149</td>
<td>24</td>
<td>18.8%</td>
</tr>
<tr>
<td>2016</td>
<td>Passias</td>
<td>JBJS</td>
<td>RO</td>
<td>243</td>
<td>24</td>
<td>16.5%</td>
</tr>
<tr>
<td>2016</td>
<td>Passias</td>
<td>Spine</td>
<td>RO</td>
<td>334</td>
<td>24</td>
<td>19.5%</td>
</tr>
<tr>
<td>2018</td>
<td>Crawford</td>
<td>Spine Deformity</td>
<td>PO</td>
<td>153</td>
<td>24</td>
<td>24.1%</td>
</tr>
<tr>
<td>2018</td>
<td>Passias</td>
<td>Neurosurgery</td>
<td>RO</td>
<td>258</td>
<td>24</td>
<td>19.4%</td>
</tr>
<tr>
<td>2021</td>
<td>Chou</td>
<td>World Magy</td>
<td>RO</td>
<td>104</td>
<td>24</td>
<td>23.1%</td>
</tr>
<tr>
<td>2021</td>
<td>Smith</td>
<td>JNSS</td>
<td>PO</td>
<td>286</td>
<td>60</td>
<td>30.9%</td>
</tr>
</tbody>
</table>
Re-operation: Comparison Across Major Surgeries

- ASD surgery is increasing in prevalence as more surgeons are comfortable with deformity corrections.
- There is no current method to categorize failure after ASD surgery.
- Categorizing failure offers several advantages to the field.

<table>
<thead>
<tr>
<th>Surgery</th>
<th>Re-operation rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASD Surgery</td>
<td>20.2%</td>
</tr>
<tr>
<td>Heart-Lung transplant</td>
<td>41.0% (5 yr f/u) [1]</td>
</tr>
<tr>
<td>Open AAA repair</td>
<td>10.0% [2]</td>
</tr>
<tr>
<td>Free Flap</td>
<td>21.6% [3]</td>
</tr>
<tr>
<td>Ped. Cardiac Surgery</td>
<td>15.0% [4]</td>
</tr>
</tbody>
</table>


Reoperation rate of 3.4%
Incremental cost-effectiveness of adult spinal deformity surgery: observed quality-adjusted life years with surgery compared with predicted quality-adjusted life years without surgery

IAN McCARTHY, PH.D.,1 MICHAEL O’BRIEN, M.D.,2 CHRISTOPHER AMES, M.D.,3 CHESSIE ROBINSON, M.A.,1 THOMAS ERRICO, M.D.,4 DAVID W. POLLY JR., M.D.,5 AND RICHARD HOSTIN, M.D.,2 ON BEHALF OF THE INTERNATIONAL SPINE STUDY GROUP

<table>
<thead>
<tr>
<th>Variable</th>
<th>3 Yr</th>
<th>5 Yr</th>
<th>10 Yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>cost ($)</td>
<td>125,407</td>
<td>125,407</td>
<td>125,407</td>
</tr>
<tr>
<td>QALYs w/ surgery</td>
<td>1.93</td>
<td>3.11</td>
<td>5.71</td>
</tr>
<tr>
<td>QALYs w/o surgery</td>
<td>1.60</td>
<td>2.47</td>
<td>4.15</td>
</tr>
<tr>
<td>QALYs gained</td>
<td>0.335</td>
<td>0.633</td>
<td>1.560</td>
</tr>
<tr>
<td>ICER ($)</td>
<td>374,428</td>
<td>198,000</td>
<td>80,387</td>
</tr>
<tr>
<td>lower 95% CI ($)</td>
<td>311,400</td>
<td>167,400</td>
<td>69,800</td>
</tr>
<tr>
<td>upper 95% CI ($)</td>
<td>455,600</td>
<td>237,000</td>
<td>93,400</td>
</tr>
</tbody>
</table>

Failures destroy cost effectiveness
Failure Prevention Drives Cost
Failure Prevention

- Double pelvis
- Double rods
- VCR rod
- BMP-2
- Ligament repair
- Vertebroplasty
- 2 surgeons
- Plastic Surgery
Process Optimization

- Benchmarking Rates-
  Comparative Measurement Error
- Human bias
- Human error
- Missing Structural/Engineering information
- Unmeasured Biologic Variation
- Control Loop Process Development

Identify the cause of the problem.
Comparative Measurement Error

- Red circles = under performers based on overall rate
Predictive Models for Benchmarking

Red circles = under performers based on predicted rate with a difference of ≥ 5%
Human Noise and Bias

A Flaw in Human Judgment

DANIEL KAHNEMAN
OLIVIER SIBONY
CASS R. SUNSTEIN

How Noise and Bias Affect Accuracy

A. Accurate
B. Noisy
C. Biased
D. Noisy and biased

SOURCE: DANIEL KAHNEMAN, ANDREW M. ROSENFIELD, LINNEA GANDHI, AND TOM BLASER FROM "NOISE," OCTOBER 2016
© HBR.ORG
“The quality of the outcome is clearly determining how people are viewing the quality of the decision. This is called 'resulting' in poker”

Patient did poorly, I should not have operated ...
Impact of a Risk Calculator on Surgeon Risk Perception and Surgical Decision Making
9 ASD Complete preoperative cases
39 surgeons (75% with >10 years experience)

- Expert surgeon ASD risk perception is heterogeneous and highly discordant.

- Surgeons tended to **overestimate** the risk of major complications and reintervention in the first 72 hours and **underestimated** the same risks at 90 days and 2 years postop.

Pellisé F et al. EuroSpine 2020
<table>
<thead>
<tr>
<th>Mean Index of Agreement (Calculator-Surgeons) Reinterventions 72h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>0.162</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean Index of Agreement (Calculator-Surgeons) Reinterventions 90d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>0.386</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean Index of Agreement (Calculator-Surgeons) Reinterventions 2y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>0.234</td>
</tr>
</tbody>
</table>
Machine – UCSF Validation - No statistically significant difference between predicted and observed rate of complications.
HOW THE SURGEON SEES IT

Frailty= .5
ODI 42
CCI 4
ASA 3
BMI 25
BMD -1.5
Cc: low back pain
Med: norco

NEAREST NEIGHBOR-ENABLING TECH

How the Machine sees it

>100 variables
Complications – Shallow to Deep

Prospective multicenter assessment of perioperative and minimum 2-year postoperative complication rates associated with adult spinal deformity surgery

Justin S. Smith, MD, PhD,1 Eric Klineberg, MD,1 Virginia Lafage, PhD,2 Christopher I. Shaffrey, MD,2 Frank Schwab, MD,2 Renaud Lafage, MS,3 Richard Hewitt, MD,4 Gregory M. Mundt Jr., MD,5 Thomas J. Erikson, MD,5,6 Ha Je Kim, MD,5 Themistocles S. Postolakis, MD,1,7 D. Kope Hamilton, MD,7 Justin X. Scherer, BS,7 Alex Semoenno, MD,1 Michael P. Kelly, MD,1 Bevan Lim, BA,8 Manish Gupta, MD,1 Veddi Devireddy, MD,1 Robert Hart, MD,10 Douglas C. Burton, MD,13 Shay Bess, MD,16 Christopher P. Ames, MD,19 and the International Spine Study Group

Number of Complications

Development and validation of risk stratification models for adult spinal deformity surgery

Ferran Pellisé, MD, PhD,1 Miquel Serra-Brunet, PhD,1 Justin S. Smith, MD, PhD,2 Steiman Haddad, MD,1 Michael P. Kelly, MD, MS,1 Alba Vila-Cassadó, MSc,1 Francisco Javier Sánchez Pérez-Grueso, MD,1 Shay Bess, MD,7 Jeffrey L. Gum, MD,1 Douglas C. Burton, MD,1 Emre Acarhuş, MD,1 Frank Kleinstück, MD,1 Virginie Lafage, PhD,12 Ibrahim Obaid, MD,1 Frank Schwab, MD,1 Christopher I. Shaffrey, MD,1 Ahmet Alanay, MD,1 Christopher Ames, MD,19 the International Spine Study Group, and the European Spine Study Group
Comparison of operative vs. nonoperative treatment for adult spinal deformity: A prospective, multi-center matched and unmatched cohort assessment with minimum 2-year follow-up.

Justin S. Smith, MD, PhD¹, Virginia Lafage, PhD², Christopher I. Shaffrey, MD², Frank Schwab, MD², Richard Hostin, MD², Olaideh Bouchie-Adji, MD², Behrouz Ailannia, MD², Eric Kleinberg, MD², Munish Gupta, MD³, Vedat Deviren, MD³, Robert Hart, MD³, Doug Burton, MD³, Shay Hess, MD³, Christopher P. Ames, MD⁴, International Spine Study Group.

GSA DATA BASE ML Calculator Output

SHALLOW DATA DEEP

DEFORMATION

Development of Deployable Predictive Models for Minimal Clinically Important Difference Achievement Across the Commonly Used Health-related Quality of Life Instruments in Adult Spinal Deformity Surgery.

Ames, Christopher P. MD², Smith, Justin S. MD, PhD²; Pellise, Ferran MD²; Kelly, Michael P. MD²; Gum, Jeffrey L. MD²; Alnay, Ahmed MD²; Acan支柱, Emre MD²; Perez-Grauso, Francisco Javier Sanchez MD²; Kleinsteuber, Frank S. MD²; Obeid, Ibraheem MD²; Via-Casademont, Alba MSC²; Burton, Douglas C. MD²; Lafage, Virginia PhD²; Schwab, Frank J. MD²; Shaffrey, Christopher I. Sr, MD²; Bess, Shay MD²; Serra-Burriel, Miguel PhD²; European Spine Study Group, International Spine Study Group.
INNOVATION 1 – PROCESS
BIAS and NOISE REDUCTION
Results to Simulation

<table>
<thead>
<tr>
<th>Simulation</th>
<th>3 days</th>
<th>30 days</th>
<th>60 days</th>
<th>90 days</th>
<th>1 year</th>
<th>2 year</th>
<th>Predictions reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial simulation</td>
<td>22%</td>
<td>34%</td>
<td>39%</td>
<td>41%</td>
<td>49%</td>
<td>53%</td>
<td>high-reliability</td>
</tr>
</tbody>
</table>

Implement and verify the solution.
## HRQoL Outcomes

<table>
<thead>
<tr>
<th></th>
<th>Likelihood of Improvement (%)</th>
<th>Likelihood of Improvement over MCID (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODI</td>
<td>87</td>
<td>62</td>
</tr>
<tr>
<td>SRS22</td>
<td>75</td>
<td>44</td>
</tr>
<tr>
<td>SRS22 MH</td>
<td>77</td>
<td>57</td>
</tr>
<tr>
<td>SRS22 pain</td>
<td>80</td>
<td>66</td>
</tr>
<tr>
<td>SRS22 SI</td>
<td>83</td>
<td>34</td>
</tr>
<tr>
<td>SRS22 subtotal</td>
<td>82</td>
<td>61</td>
</tr>
<tr>
<td>SF36 MCS</td>
<td>62</td>
<td>26</td>
</tr>
<tr>
<td>SF36 PCS</td>
<td>84</td>
<td>66</td>
</tr>
</tbody>
</table>
Results: QALY

- The mean 2yr QALYs gained/patient was 684% greater using MACHINE SELECTION VS SURGEON (0.0046 vs. 0.0007)
Use of Predictive Machine Learning Models at the Population Level Has the Potential to Save Cost by Directing Economic Resources to Those Likely to Improve Most:

A Simulation Analysis Stratified by Risk in Largest Combined US/European ASD Registry

Rushikesh S. Joshi, BS; Miquel Serra-Burriel, PhD; Ferran Pellise, MD; Darryl Lau, MD; Justin S. Smith, MD, PhD; Michael Kelly, MD; Ahmet Alanay, MD; Emre Acaroglu, MD; Francisco Javier Sanchez Perez-Grueso, MD; Frank Kleinstuck, MD; Ibrahim Obeid, MD; Douglas Burton, MD; Virginie Lafage, PhD; Frank Schwab, MD; Christopher I. Shaffrey Sr, MD; Shay Bess, MD; Christopher P. Ames, MD; European Spine Study Group, International Spine Study Group

NASS Annual Meeting 2020
9/9/20
Finding Responders Prior to Spend

- Simulation:
  - >50% chance of MCID improvement and complication rate <20%
  - Corresponding to 407/1245 = 33%

- Extrapolated to real-world populations
  - ASD surgery in US (2013):
    - 6728 -> 2220; rate: 13.85 -> 4.57
    - $541 million cost savings
  - ASD surgery in Spain (2015):
    - 740 -> 244; rate: 1.64 -> 0.54

I

Improve

Implement and verify the solution.
Simulations using 2019 Models

- >50% chance of MCID
  - Decrease surgery by 16%
- <50% chance of MC
  - Decrease surgery by 28%
- >50% chance of MCID and <50% MC
  - Decrease rate of surgery by 41%
  - Reduction of spend in US >500 million

*SRS 2020*
AI in Healthcare

SHALLOW -----> DEEP

How to Shift from Selling Products to Selling Services
hbr.org • 10 min read
The Sagittal Plane Revisited

- Overall R2: SVA

![Graphs showing correlation between ODI and SVA](image)

ISSG Scheer SRS Submitted 2022
**Risk mechanical complications GAP score**

![Graph showing predicted probability (%) vs GAP score]

### GAP SCORE (Global Alignment and Proportion)

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>SCORING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Relative Proximal Version (RPV)</strong></td>
<td><strong>Score</strong></td>
</tr>
<tr>
<td>Severe Retroversion</td>
<td>&lt; 15</td>
</tr>
<tr>
<td>Moderate Retroversion</td>
<td>15 - 25</td>
</tr>
<tr>
<td>Mild Retroversion</td>
<td>26 - 35</td>
</tr>
<tr>
<td>Anteversion</td>
<td>&gt; 36</td>
</tr>
<tr>
<td>Ideal Slope ± 10°</td>
<td>1</td>
</tr>
</tbody>
</table>

| **Relative Lumbar Lordosis (PLL)** | **Score** |
| Severe Hypoplasia | < 25 | 3 |
| Moderate Hypoplasia | 25 - 40 | 2 |
| Mild Hypoplasia | 40 - 50 | 1 |
| Ideal Lordosis ± 10° | 0 |

| **Lordsis Distribution Index (LDI)** | **Score** |
| Severe Hypoplasia | < 40° | 3 |
| Moderate Hypoplasia | 40° - 60° | 2 |
| Mild Hypoplasia | 60° - 90° | 1 |
| Ideal Distribution ± 10° | 0 |

| **Relative Spine-pelvic Alignment (RSA)** | **Score** |
| Severe Malalignment | > 18° | 3 |
| Moderate Malalignment | 18° - 30° | 2 |
| Mild Malalignment | 30° - 45° | 1 |
| Ideal Global Tilt ± 10° | 0 |

| **Age Factor** | **Score** |
| Child | 0 |
| Adult | 1 |

**Fig. 4:** The GAP score. The parameters column includes a scale-based view of the subgroups of each parameter using the cutoff points. The scoring column includes the calculated value of the parameters subgroups. The categories column includes the categorization of the GAP score.
Mechanical Complications Have a Far Greater Impact on Clinical Outcomes than Other Perioperative and Postoperative Complications in ASD Surgery

- Retrospective cohort study of 762 ASD patients.
- Complications:
  - 317 (42%) radiographic unrelated to PJF
  - 135 (17.7%) neurological
  - 245 (32.2%) medical complications
  - 545 (71.5%) mechanical after discharge
  - 248 (32.5%) intra/perioperative
  - 17 (2.2%) surgical infection related
- Radiographic complications had the most impact on ODI and SRS, followed by neurological complications.
HUMAN ERROR AND NOISE IN REALIGNMENT

Rod Bending Accuracy

In Sardi et al., ten experienced surgeons were asked to contour rods using a French Bender to 40, 60, and 80 degrees. Without a template, surgeons overbent by a mean of 17.5 to 26.2 degrees for each desired angle, but with a template, they came within an average of two degrees of their target angle.

Average Difference from Target Angle

- 20.2 with 1.5 without template
- 18.9 with -0.9 without template
- 17.5 with -1.3 without template

Global Spine J
. 2021 Feb 25;2192568221998371.

Accuracy of Rod Contouring to Desired Angles With and Without a Template: Implications for Achieving Desired Spinal Alignment and Outcomes
Juan Pablo Sardi 1, Christopher P Ames 2, Skye Coffey 3, Christopher Good 4, Benny Dahl 5, Paul Kraemer 6, Jeffrey Gum 7, Dennis Devito 8, Marco Brayda-Bruno 9, Robert Lee 10, Christopher P Bell 11, Shay Bess 12, Justin S Smith 1
# Impact of Error

Under corrected by 16 degrees

<table>
<thead>
<tr>
<th></th>
<th>Pre-Op</th>
<th>Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT</td>
<td>23</td>
<td>18</td>
</tr>
<tr>
<td>PI</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>LL</td>
<td>-2</td>
<td>32</td>
</tr>
<tr>
<td>PI-LL</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>TK</td>
<td>23</td>
<td>35</td>
</tr>
<tr>
<td>SVA</td>
<td>201</td>
<td>89</td>
</tr>
</tbody>
</table>

Properly Corrected

<table>
<thead>
<tr>
<th></th>
<th>Pre-Op</th>
<th>Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT</td>
<td>23</td>
<td>16</td>
</tr>
<tr>
<td>PI</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>LL</td>
<td>-2</td>
<td>42</td>
</tr>
<tr>
<td>PI-LL</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>TK</td>
<td>23</td>
<td>37</td>
</tr>
<tr>
<td>SVA</td>
<td>201</td>
<td>0</td>
</tr>
</tbody>
</table>

16 degree LL bend error results in 9cm SVA difference
Reciprocal Change Prediction?

Can Human Intelligence compete with machines here?
Custom Rods – ML

>10,000 cases ML Predicts ….

- Thoracic Compensation in Adults
- Pelvic Compensation
- Lumbar Compensation in PEDS
- Cervical Compensation …
Prediction of Failure in Dynamic Structures

Architect → Structural Engineer → Success or Failure

Structural Engineering

Loading
Force
Fatigue

Implement and verify the solution.
Can we Predict/PLAN for Failure in the planning stage using structural analysis?
ASD Causality: *Directed Acyclical Graphs*
Observational setting: 2-Year Oswestry results

1) Effect of surgery on 2-Y Oswestry: 12 $\Delta$, $R^2 = 14\%$
2) Effect of surgery on 2-Y Oswestry: 10 $\Delta$, $R^2 = 18\%$
3) Effect of surgery on 2-Y Oswestry: 8 $\Delta$, $R^2 = 20\%$
4) Effect of surgery on 2-Y Oswestry: 5.6 $\Delta$, $R^2 = 28\%$

Site, Demographics, x-rays, Proms

4)
There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we know we don't know. But there are also unknown unknowns. There are things we don't know we don't know.

(Donald Rumsfeld)
Rod fracture occurred in 9.5% of patients with apparently solid fusion after ASD surgery.
Unmeasured Biologic Variation

RISK TESTING
MODIFICATION
TRACKING

Metabolon
ENLIGHTENING LIFE
Impact of age on the likelihood of reaching a minimum clinically important difference in 374 three-column spinal osteotomies

Clinical article

JUSTIN K. SCHEER, B.S.,† VIRGINIE LAFAGE, Ph.D.,† JUSTIN S. SMITH, M.D., Ph.D.,† VEYDAY DEVIREN, M.D.,‡ RICHARD HOSTIN, M.D.,† IAN M. MCCARTHY, Ph.D.,† GREGORY M. MUNDIS, M.D.,§ DOUGLAS C. BURTON, M.D.,∥ ERIC KLEINBERG, M.D.,∥ MUNCHI C. GUPTA, M.D.,∥ KEALED M. KEBADISH, M.D.,∥ CHRISTOPHER I. SHEAFFEY, M.D.,∥ SHAY BENS, M.D.,∥ FRANK SCHWAR, M.D.,∥ CHRISTOPHER P. AMES, M.D.,∥ AND THE INTERNATIONAL SPINE STUDY GROUP (ISSG)

Fig. 2. Percentage of patients reaching the MCID for the PCS in the PSO group. Asterisks indicate statistically significant difference between groups connected by the horizontal line (p < 0.05).
Results – Age vs Telomere Length

Genetic age is distinct from chronological age
As is Bone Age
Muscle Age
....
## Telomere Length as a Surgical Risk Tool

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds ratio (95% CI)</th>
<th>Significance (p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age ≥ 65</td>
<td>3.313 (0.276 – 39.691)</td>
<td>0.344</td>
</tr>
<tr>
<td>Frail or Severely Frail</td>
<td>0.819 (0.101 – 6.606)</td>
<td>0.851</td>
</tr>
<tr>
<td>ASA class 3</td>
<td>5.113 (0.524 – 49.925)</td>
<td>0.160</td>
</tr>
<tr>
<td>Anterior-posterior surgery</td>
<td>0.237 (0.036 – 1.548)</td>
<td>0.133</td>
</tr>
<tr>
<td>Charlson comorbidity index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-1</td>
<td>Reference</td>
<td>0.715</td>
</tr>
<tr>
<td>2-3</td>
<td>4.322 (0.212 – 88.165)</td>
<td>0.341</td>
</tr>
<tr>
<td>4-5</td>
<td>5.745 (0.118 – 278.992)</td>
<td>0.378</td>
</tr>
<tr>
<td>6-7</td>
<td>16.175 (0.132 – 1,979.213)</td>
<td>0.256</td>
</tr>
<tr>
<td>Telomere length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4th quartile (longest)</td>
<td>Reference</td>
<td>0.155</td>
</tr>
<tr>
<td>3rd quartile</td>
<td>5.438 (0.528 – 55.963)</td>
<td>0.155</td>
</tr>
<tr>
<td>2nd quartile</td>
<td>3.832 (0.368 – 39.909)</td>
<td>0.261</td>
</tr>
<tr>
<td><strong>1st quartile (shortest)</strong></td>
<td><strong>26.630 (1.577 – 449.658)</strong></td>
<td><strong>0.023</strong></td>
</tr>
</tbody>
</table>

### Shorter telomere length associated with increased risk of complication

*Telomere PCR

---

SRS HIBBS AWARD 2021
BLOOD TEST OF FRAILTY

- ASD frailty index
  - Disease-specific

- Epigenetic clock based on rate of aging (DunedinPACE)
  - Correlates with frailty

- Genetic basis of frailty?
Composite OMICS Score

Superior

PCA inferior to simple sum composite score
The Power of Loop Ecosystem – Control
“LOST CLINICAL DATA IS A LOST OPPORTUNITY TO IMPROVE CARE AND TRAIN”
Idiopathic scoliosis
A historical overview

Serena S. Hu, MD
Professor and Vice Chair
Chief, Spine Service
Department of Orthopedic Surgery
Professor, by courtesy
Department of Neurological Surgery
Stanford University
Disclosures

- Board membership:
  - American Orthopedic Association
  - Scoliosis Research Society
- Journal editorial roles:
  - Global Spine Journal (deputy editor)
  - Spine Deformity (editorial board)
- Intellectual property:
  - OnPoint
  - MiRus
Early management of scoliosis

- Hippocrates described longitudinal traction in 5 BC.
- Galen of Pergamum: added direct pressure 2C AD
- Pare (Fr) described supportive braces 1500’s, thinking deformity was from dislocation of spine
- Sayre (Bellevue, NYC): first Professor of Orthopedic Surgery in US, believed scoliosis caused by muscular imbalance so treatment should be “gymnastic exercises”
  - 1874: traction with plaster cast to correct spine deformity
- 1895 Roentgen (German physicist) discovered x-rays
- TB of spine
- Poliomyelitis
SCOLIOSIS

ROTARY LATERAL CURVATURE
OF THE SPINE

BY

SAMUEL KLEINBERG, M.D., F.A.C.S.
Assistant Surgeon, New York Hospital for Ruptured and Crippled
Member of the American Orthopedic Association
Chief of Orthopedic Service, Israel Zion Hospital of Brooklyn
Consulting Orthopedic Surgeon, Rockaway Beach Hospital
Attending Orthopedic Surgeon, Israel Orphan Asylum
Associate Surgeon, Lebanon Hospital
New York

Society for the Ruptured and Crippled
1946
Thanks to David B. Levine

- Founding member of SRS (made suggestion as a fellow)
- 4th chief of scoliosis surgery at HSS

1968-1994
Early treatment: physio

“keynote position”
Early treatment “forcible correction”

Wullstein plaster

Adams frame

Lovett traction table

Abbott progressive padding

Kleinberg
Successful treatment

**Fig. 116A.** H. F. Feb. 11, 1913.
Rigid left dorsal curve. Treated with Abbott jackets.

**Fig. 116B.** H. F. April 2, 1914.
Shows practically complete correction of curve of spine.
Russell Hibbs (1869-1932)

- Surgeon-in-Chief
- New York Orthopedic Dispensary and Hospital
- 1911: First described spinal fusion
  - Pott’s disease
John R. Cobb (1903-1967)

- First chief of scoliosis service at R&C 1935
  - Use of turnbuckle cast
  - Staged spinal fusion
- Cobb angle
- Cobb elevator

"You don’t have to be crazy to do scoliosis, but it helps"
14 yo treated at RCC: 2 m post op: tibial strut (after Albee)
Preop casting, post op casting, bedrest
• 425 cases
• 214 (50%) fusions after failed conservative Rx
  • Turnbuckle jacket for 80%
  • Avg correction 65%
  • Avg correction at end of Rx 27%
  • Bone grafts 60%
  • 28% pseudo
  • 3 months recumbency for 47%
  • 69% fair or poor
  • 31% good or excellent

END-RESULT STUDY OF THE TREATMENT OF IDIOPATHIC SCOLIOSIS
Report of the Research Committee of The American Orthopaedic Association

A. R. SHANDS, JR.  JOSEPH S. BARR  PAUL C. COLOUNA  LAWRENCE NOALL

JBJS: 1941
John H. Moe, MD

- Founded scoliosis service at Gillette
- Founding president SRS 1964
- Cobb measurement
- Cobb elevator
- Used Risser localizer cast, Milwaukee brace
- 1958: 15% pseudo rate
Risser localizer cast

- Joseph Risser 1892-1982
- Protégé of Russell Hibbs
- Risser sign 1958
Walter Blount, MD

- Milwaukee brace (CTLSO)
- Originally for post op Polio
- 1958: non-op Rx AIS
- Could cause mandible deformities
G Dean MacEwen, MD

- Chief at DuPont Institute
- 1969: patient refused Milwaukee brace despite “extensive counseling”
- → TLSO “Wilmington brace”

Custom TLSO made on Risser frame with traction, lateral straps
Founding of the Scoliosis Research Society

June 1966
Morbidity and mortality

M&M committee report
Chaired by MacEwen
Neurologic complications
Artery of Adamkiewicz T8-L3
Stretch during correction
Death within one year
Marc A. Asher, MD

- 1936-2019
- LTA from POSNA, SRS
- Published Dogged Persistence 2015
- Labor of Love
- Harrington papers at UK
Paul R Harrington, MD

- 1966 AAOS
- Presented ICL “Scoliosis and instrumentation”
- Met Melvin Glimcher speaking about “structure and organization of bone”
- Visited Enneking in FL to discuss facet histology
- V resistant to autograft bone
  - Preferred calf bone
  - Setup processing to minimize reactivity
- 1974: TiVanium testing
Paul Harrington: worked with Zimmer

Original design

Self-adjusting spine strut

Harrington fusion with outrigger

Royalties were fixed payment, e.g., distraction-compression 8-hook construct $59.75, royalty to Harrington $5 or 3%. Did not adjust for inflation. Zimmer had exclusive rights.

1962: 4 quarters’ royalties $3,762.50

No patents, example being Salk polio vaccine and funding from National Foundation (NFIP)
Pedicle screw instrumentation for spondylo reduction
David Levine: first H rod at HSS
Alan Dwyer (1920-1975)

- Visited Arthur Hodgson HK
- Idea of excising wedges from anterior spine
- 1969 CORR

- Died at age 55, cancer of esophagus
John Hall

- 1969 President SRS
- Pulmonary function as focus of meeting
- Arm span to determine pulmonary function deficit
- Curves > 60°

- Reported on 32 patients
  Dwyer instrumentation
Clyde "Les" Nash, Jr

- 1971 Spinal cord monitoring
  - Cat model
  - Role of BP in cortical evoked potential

- 1975 w Winter, Simmons, Dickson, established Harrington Guest Lecturership

- 1932-2019

Senior traveling fellow
Pierre Stagnara

- 1972 presented on wakeup test 124 patients
- Previously had established organized non-surgical approach with casts and braces “Lyonnaise school”
- Early treater of complex adult deformity, led to wakeup test
- Recognized “kyphosing scoliosis” and 3D nature

1917-1995

Dubousset. Spine 1996
Eduardo Luque Rebollar

- 1931-2001 (Spanish-Mexican)
- Stanford undergrad and med school
- Internship at McGill
- Residency: LAOH w Risser
- Segmental spinal instrumentation
  - Multiplanar correction
  - No postoperative immobilization
Klaus Zielke

- 1977
- Threaded anterior rod, nuts that could be repeatedly adjusted
  - Derotation rod (VDS)
  - Presented 56 cases
- Addressed the flexibility of Dwyer, creation of kyphosis, lack of adjustability
- John Hall and Lyle Micheli presented Dwyer with solid Ti rod
• King Moe classification
• 29 year experience
• 455 patients
• Lumbar fusion only needed in 13.9% of patients

Stable zone of Harrington
Cotrel-Dubousset instrumentation

• 1984 to US
• 3D correction
  • Derotation, distraction, compression, translation
• Rigid and stable enough to eliminate bedrest and cast
• $3000 v $300 for Hrod

Shufflebarger and Clark, Ortho 1988
**ADOLESCENT IDIOPATHIC SCOLIOSIS**

A NEW CLASSIFICATION TO DETERMINE EXTENT OF SPINAL ARTHRODESIS

BY LAWRENCE G. LENKE, MD, RANDAL R. BETZ, MD, JURGEN HARMS, MD, KEITH H. BRIDWELL, MD, DAVID H. CLEMENTS, MD, THOMAS G. LOWE, MD, AND KATHY BLANKE, RN

---

### Curve Type

<table>
<thead>
<tr>
<th>Type</th>
<th>Proximal Thoracic</th>
<th>Main Thoracic</th>
<th>Thoracolumbar / Lumbar</th>
<th>Curve Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Non-Structural</td>
<td>Structural (Major*)</td>
<td>Non-Structural</td>
<td>Main Thoracic (MT)</td>
</tr>
<tr>
<td>2</td>
<td>Structural</td>
<td>Structural (Major*)</td>
<td>Non-Structural</td>
<td>Double Thoracic (DT)</td>
</tr>
<tr>
<td>3</td>
<td>Non-Structural</td>
<td>Structural (Major*)</td>
<td>Structural</td>
<td>Triple Major (TM)</td>
</tr>
<tr>
<td>4</td>
<td>Structural</td>
<td>Structural (Major*)</td>
<td>Structural</td>
<td>Thoracolumbar / Lumbar (TL/L)</td>
</tr>
<tr>
<td>5</td>
<td>Non-Structural</td>
<td>Structural (Major*)</td>
<td>Structural</td>
<td>Main Thoracic (TL/L - MT)</td>
</tr>
<tr>
<td>6</td>
<td>Non-Structural</td>
<td>Structural</td>
<td>Structural</td>
<td></td>
</tr>
</tbody>
</table>

---

**STRUCTURAL CRITERIA**

(Minor Curves)

- **Proximal Thoracic:** Side Bending Cobb ≥ 25°
- **Main Thoracic:** T2 - T5 Kyphosis ≥ 20°
- **Thoracolumbar / Lumbar:** Side Bending Cobb ≥ 25°
- **Thoracolumbar / Lumbar:** T10 - L2 Kyphosis ≥ 20°

*Major = Largest Cobb Measurement, always structural
Minor = all other curves with structural criteria applied

**LOCATION OF APEX**

(SRS definition)

- **CURVE:** THORACIC
- **APEX:** T2 - T11-12 DISC
- **THORACOLUMBAR:** T12 - L1
- **LUMBAR:** L1-2 DISC - L4

---

### Modifiers

<table>
<thead>
<tr>
<th>Lumbar Spine Modifier</th>
<th>CSVL to Lumbar Apex</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>CSVL Between Pedicles</td>
</tr>
<tr>
<td>B</td>
<td>CSVL Touches Apical Body(ies)</td>
</tr>
<tr>
<td>C</td>
<td>CSVL Completely Medial</td>
</tr>
</tbody>
</table>

**Thoracic Sagittal Profile**

- **T5 - T12**
  - (Hypo) < 10°
  - (Normal) 10°- 40°
  - (Hyper) > 40°

---

**Curve Type (1-6) + Lumbar Spine Modifier (A, B, or C) + Thoracic Sagittal Modifier (- , N, or +)**

Classification (e.g. 1B+):________
Did the Lenke Classification Change Scoliosis Treatment?

David H. Clements, MD,* Michelle Marks, PT, MA,† Peter O. Newton, MD,‡ Randal R. Betz, MD,* Lawrence Lenke, MD,§ Harry Shufflebarger, MD,¶ and Harms Study Group

<table>
<thead>
<tr>
<th>Curve Type</th>
<th>No. of Patients in Database</th>
<th>Before 2001, % of “Rule-breakers”</th>
<th>After 2001, % of “Rule-breakers”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lenke 1</td>
<td>781</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>Lenke 2</td>
<td>175</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td>Lenke 3</td>
<td>66</td>
<td>22</td>
<td>29</td>
</tr>
<tr>
<td>Lenke 4</td>
<td>44</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>Lenke 5</td>
<td>182</td>
<td>34</td>
<td>19</td>
</tr>
<tr>
<td>Lenke 6</td>
<td>62</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>1310</td>
<td>18</td>
<td>12</td>
</tr>
</tbody>
</table>
SI Suk: thoracic pedicle screws

- 1995: 78 AIS patients treated 1987-91
  - 31 hooks $\rightarrow$ 55% correction
  - 23 screws $\rightarrow$ 66%
  - 24 segmental screws $\rightarrow$ 72%
    - Improved compensatory curve correction
    - Rotational correction
  - Suk+ Spine 1995

Suk+ ESJ 2012
Thank you
Challenges in Surgery

Scoliosis in the Child and in the Adult

Sigurd Berven, M.D.
Professor in Residence
Chief of Spine Service,
Department of Orthopaedic Surgery
University of California
San Francisco

Outline

• Deformity in the Pediatric Spine is distinct from Adult Deformity
  – Curve Patterns
  – Clinical symptoms
  – Natural History
• Goals of Care
  – Improvement of Health-related Quality of Life (QALY)
  – Avoidance of future disability (DALY)
• Advantages/Risks of Early Surgical Intervention
• Advantages/Risks of Observation into Adulthood
• Making informed Choices
  – Patient Values and Preferences
Pediatric Spinal Deformity

• Scoliosis:
  – Congenital
  – Neuromuscular
  – Syndromic
  – Idiopathic

• Sagittal Plane Malalignments
  – Scheuermann Kyphosis
  – Spondylolisthesis
Pediatric Spinal Deformity

- **Scoliosis:**
  - Congenital
  - Neuromuscular
  - Syndromic
  - Idiopathic

- **Sagittal Plane Malalignments**
  - Scheuermann’s Kyphosis
  - Spondylolisthesis
Pediatric Spinal Deformity

• Scoliosis:
  – Congenital
  – Neuromuscular
  – Syndromic
  – Idiopathic

• Sagittal Plane Malalignments
  – Scheuermann’s Kyphosis
  – Spondylolisthesis
Pediatric Spinal Deformity

- Scoliosis:
  - Congenital
  - Neuromuscular
  - Syndromic
  - Idiopathic

- Sagittal Plane Malalignments
  - Scheuermann’s Kyphosis
  - Spondylolisthesis

- John Hall, MD
  - The decision of whether or not to operate is far more important than the decision of how to do the surgery.
Transition from Adolescent to Adult

• When to Operate on the adolescent
  – Natural History
  – Clinical Presentation

• When to Observe into Adulthood
  – Which adolescent developmental conditions progress to symptomatic adult pathology

Timing of Surgical Interventions
Timing of Surgical Interventions

Perspective

- Patient Perspective
- Parent Perspective
- Physician Perspective
Why do Adults Choose to Have Surgery for Scoliosis

- Pain Control
- Function Improvement
  - Neural Improvement
- Deformity Correction
- Concern for Future Consequences
Why do Adolescents Choose to Undergo Surgery for Idiopathic Scoliosis?

1) Concern Regarding **Future Consequences**
2) Appearance
3) Reduce Present Pain
4) Limit Levels Fused
5) Return to Function

Defining the Goals of Care

- Correction of deformity
- Prevention of Progression
- Improvement of health-related quality of life
  - General health status
  - Disease-specific health status
- Avoidance of future consequences of Deformity Progression
What are the Consequences of Deformity Progression

- Cardiopulmonary Disease
- Mortality
- Neural impairment
- Pain
- Disability
- Appearance/Social Role

Empowering Informed Choice in the Management of Pediatric Deformity

- Natural History
- Correlation of Disease Progression with Disability
- Patient Preference/Values
Pediatric Spinal Deformity

• Scoliosis:
  – Congenital
  – Neuromuscular
  – Syndromic
  – Idiopathic

• Sagittal Plane Malalignments
  – Scheuermann’s Kyphosis
  – Spondylolisthesis

- Retrospective analysis; Sweden
- 115 pts
  i. post-polio (26), rickets (19), idiopathic (69)
  ii. infantile (29), juvenile (32), adolescent (52)
- Death certificates analyzed (54 deaths)
- Compared to population of same age and sex according to official registries
Mild: < 40
Moderate: 40 - 70
Severe: > 70
- Retrospective analysis

- 131 pts - idiopathic; unfused; chest clinic over 25 years

- Age of curve onset
  - <5: 15
  - 5-10: 10
  - 10-20: 24
  - >20: 4

- Curve severity ~ “severe” (60-90)

- Dyspnea ~ 25% (Primarily when FVC <50%)

### Table 1. Outcome related to age of onset

<table>
<thead>
<tr>
<th>Age</th>
<th>Number</th>
<th>No. with cardioresp. failure or disabling dyspnea</th>
<th>Associated cardiac or respiratory disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5</td>
<td>15</td>
<td>11</td>
<td>28</td>
</tr>
<tr>
<td>5-10</td>
<td>10</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>10-20</td>
<td>24</td>
<td>3 (mild in 2)</td>
<td>5 (graves in all 5)</td>
</tr>
<tr>
<td>&gt;20</td>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 117pts with Late Onset AIS who presented between 1932-1948
  - Comparison with 62 age/gender matched controls

**Main Outcome Measures**
- Mortality, back pain, pulmonary symptoms, general function, depression, and body image.

**Conclusions**
- Untreated adults with LIS are productive and functional at a high level at 50-year follow-up. Untreated LIS causes little physical impairment other than back pain and cosmetic concerns.
When do we Operate During Adolescence and When should we Observe into Adulthood?
• Rate of deterioration and ultimate severity is determined by both curve type and curve location.
• Patient with congenital kyphosis have a high rate of deformity progression
• High rate of neural injury in patients with untreated type 1 deformity
• Before age 3, posterior approach may be appropriate for Type 2 and 3 deformity
Standing post-op
2013

Standing 12/2016

Standing X-rays
Standing postop
18 yo Girl born in Guatemala

- **PMH**
  - Noonan’s Syndrome with Associated NF-1
  - Mitral Valve Stenosis s/p replacements on Anti-coag
- **Spine Hx**
  - Curve Never Treated
  - Dysplastic Apical changes including wedged vertebrae
  - Untreated Restrictive Lung Disease
- **Neurologically intact**
- **Ambulatory but not athletic**

Vertebral Column Resection
Noonan’s Syndrome

- Heterogeneous condition characterized by:
  - unique facial features,
  - short stature,
  - chest deformity,
  - congenital heart disease,
  - spinal deformities
- Incidence of NS estimated to be 1 in 1,000-2,500 live births

Association with Neurofibromatosis (NF-1)

- Most Common Single Gene Disorder (1 / 3000 live births for NF-1)
- Von Recklenhausen’s Disease - Chromosome 17q21 – Autosomal Dominant
- Diagnostic Criteria (2 or more)
  - Café-Au-Lait Spots - Neurofibromas - Freckling
  - Optic Glioma - Lisch Nodules - Osseous Lesion
- Most Common Skeletal Anomaly: Scoliosis
  - Non-Dystrophic - Dystrophic
Vertebral Column Resection

Sagittal: 120° from T5 - T12

Coronal: 106° from T5 - T12
DISCUSSION

- Further Imaging
- Assessment of Flexibility
- Syndromic / Neuromuscular Scoliosis Considerations
- Patient counseling
- Treatment options
Timing of Surgery for AIS

- Understanding Natural History of Deformity Progression
- Flexibility
- Role of Lumbar Curve (L,R)
- Equipose:
  - Type 3C curves
  - Type 1AL curves

17yo female
Lenke 3CN
  - Thoracic T6-T12= 52
  - Lumbar T12-L4= 34
No pain or limitations
Scholarship to run 400m hurdles
- Matched Cohort analysis – 160 patient
- Adolescent surgery (ave age 14) compared with adult surgery (ave age 22) for AIS/AdIS
- Better curve correction in the adolescent
- Possible lower risk of distal junctional deformity in young adult surgery
- No difference in health status

17yo female
- Lenke 3CN
  - Thoracic T6-T12= 52
  - Lumbar T12-L4= 34
- No pain or limitations
- Scholarship to run 400m hurdles
• 14yo female with progressive thoracic structural curve and progression of lumbar rotation
  • T4-10= 62
  • T10-L3= 32 (18)
  • 3CN deformity
• 36 patients with selective thoracic fusion for Lenke 3C deformity
  – 10/36 (28%) with significant progression of deformity 2 years after surgery
  – Lumbar rotation on bending films is a predictor of progressive deformity of the lumbar spine after selective thoracic fusion
• 32 patients with 1C deformity and minimum 5 year follow-up
• 2/32 required revision surgery
• Predictors of revision
  – Lumbar Apical rotation
  – Lumbar Apical Translation
  – Lumbar curve magnitude
  – Lumbar Sagittal Alignment
11 yo female
Lenke 4CN
Thoracic T2-T11 78
Lumbar T11 L3 68
• 16+4yo female
• Lenke 6CN deformity
  – T5-T12  46 degrees
  – T12-L4  52 degrees
• Dancer and volleyball player
• Dissatisfied with spine appearance
• Mild thoracolumbar pain
• 14yo female with left ventricular hypoplasia and prior Fontan Procedure as an infant
• Lenke 4CN
  – T6-T12 75
  – T12-L4 78
• Presents with mild pain to thoracolumbar spine, dyspnea with exercise and progressive deformity
• 36yo female, laboratory technician
• Mother of 2 girls age 3,5
• Scoliosis diagnosed age 12
• Progressive pain to lumbosacral spine with left L5 radiculopathy
• 6CN deformity
- 32yo female
- Works in marketing
- Active in hiking and yoga
- Moderate thoracic pain to right periscapular region
- Dissatisfied with appearance
- 1BN deformity
• Intraoperative assessment of Alignment
• 17yo female
  – First noticed spinal deformity age 12
  – Recruited as college volleyball player
• Lenke 1AN (L)
  – Thoracic T7-L1  54
  – Lumbar L1-L4  25

16yo female
1AN (R) curve
78 degrees T4 to L1
Brace since age 12
Predictors of Distal Adding-on in Thoracic Major Curves With AR Lumbar Modifiers

Joshua S. Murphy; Vidyadhar V. Upasani; Burt Yaszay; Tracey P. Bastrom; Carrie E. Bartley; Amer Samdani; Lawrence G. Lenke; Peter O. Newton

- 160 patients
- 17% with distal adding on
- Risk Factors:
  - Preoperative coronal alignment
  - Skeletal Immaturity
  - Fusion short of LSTV
    - Lowest Substantially Touched Vert

16yo female
1AN (R) curve
78 degrees T4 to L1
Brace since age 12
12yo female
Lenke 1BN
Thoracic T4-11  56
Lumbar T11-L4  34
The Promise of New Technology

11 yr.

50° 45°
Conclusions

• Timing of Surgery in Pediatric Deformity requires knowledge of natural history of disease and outcomes of care

• Early surgery for:
  – Early onset deformity
    • Congenital scoliosis/kyphosis
    • Infantile/Juvenile progressive
  – Syndromic and neuromuscular deformity
  – Dysplastic spondylolisthesis

• Consider delayed surgery for:
  – Late onset AIS
    • Type 1A deformity
    • Type 4, 6 C curves
    • Thoracic deformity <60 degrees with Lenke AR lumbar modifier
C5 PALSY

Vincent C. Trayanis
Rush University Medical Center
Chicago

DISCLOSURES

Consultant: Medtronic, NuVasive
Royalties: Medtronic

C5 PALSY

- Usually unilateral weakness of the deltoid and biceps either immediately or several days following surgery involving the C45 level
- May be sensory deficits, pain, could be bilateral
- Majority of patients recover in 6 – 12 months

INCIDENCE OF C5 PALSY

Anterior surgery: 0 - 14%
Posterior surgery: 0 - 24%
- Epstein, Hollingsworth Surg Neuro Int 2014

Pooled incidence after posterior decompression 5.8%
- Gu et al Plos One 2014

Most studies are observational, retrospective
RCT INCIDENCE OF C5P

• Overall 26 RCTs
• 2060 patients
• 19 cases C5P
• 9.2 cumulative incidence per 1000
  • (0.92%)
### RCT Incidence of C5P

<table>
<thead>
<tr>
<th></th>
<th>Cases (N)</th>
<th>Total Sample (N)</th>
<th>Cumulative Incidence per 1000 (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Myelopathy Total</strong></td>
<td>19</td>
<td>1201</td>
<td>15.8 (10.1-24.8)</td>
</tr>
<tr>
<td><strong>Posterior</strong></td>
<td>15</td>
<td>697</td>
<td>21.5 (13.0-35.7)</td>
</tr>
<tr>
<td><strong>Anterior</strong></td>
<td>4</td>
<td>504</td>
<td>7.9 (3.0-21.1)</td>
</tr>
<tr>
<td><strong>Radiculopathy Total</strong></td>
<td>0</td>
<td>1059</td>
<td>0 (0-7.5)</td>
</tr>
<tr>
<td><strong>Posterior</strong></td>
<td>0</td>
<td>44</td>
<td>0 (0-181.7)</td>
</tr>
<tr>
<td><strong>Anterior</strong></td>
<td>0</td>
<td>815</td>
<td>0 (0-7.9)</td>
</tr>
</tbody>
</table>

### C5 Palsy

- **Six Prior Systemic Reviews Incidence:** 52 – 78 /1000
  - Gu 2014
  - JACK 2019
  - PIN 2017
  - SIRO 2015
  - Takase 2020
  - Yoshihara 2019

- **Retrospective**
  - 13,946 Patients
  - 59 with C5 Palsy 0.41\%
  - (0 – 2.5% range over sites)
RCT C5 PALSY
• Provided data on severity and duration
• Most patients developed weakness early
• Immediate or <3 days post-surgery
• Most patients recovered in 4 days to 6 months
• Not all patients recovered
C5 VULNERABILITY
• Shorter rootlets than other cervical nerve roots
• A more horizontal course to the vertebral foramen
• The smallest cervical nerve root in cross-sectional area
• C4-5 has the most anteriorly protruding zygapophyseal joints
• C45 at or near the apex of decompression
• There are more numerous and robust foraminal ligaments within the C4-5 intervertebral foramen.

Postoperative Delayed Cervical Palsies: Understanding the Etiology
Ryan F. Manchon1, Patrick R. Maloney1, Grant W. Mallory1, Ross C. Puffer1, Robert J. Spillner1, Ahmad Naser2, Jeremy L. Fogelhorn1, William E. Kraus1, Michelle J. Clarke1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Univariate analysis</th>
<th>Multivariate analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>OR (95% CI) p Value</td>
<td>OR (95% CI) p Value</td>
</tr>
<tr>
<td>Age (per year)</td>
<td>1.02 (1.008-1.036) 0.001</td>
<td>1.01 (1.001-1.027) 0.015</td>
</tr>
<tr>
<td>History of other autoimmune disease</td>
<td>3.83 (1.41-10.78) 0.001</td>
<td>2.95 (1.04-8.092) 0.041</td>
</tr>
<tr>
<td>Intraoperative transfusion</td>
<td>2.57 (1.15-5.32) 0.023</td>
<td>0.85 (0.34-1.50) 0.056</td>
</tr>
<tr>
<td>Number of levels (per level)</td>
<td>1.42 (1.07-1.89) 0.005</td>
<td>1.27 (1.07-1.48) 0.005</td>
</tr>
<tr>
<td>Posterior fusion</td>
<td>0.63 (0.35-1.10) 0.076</td>
<td>0.75 (0.36-1.60) 0.021</td>
</tr>
<tr>
<td>Scoliosis</td>
<td>0.29 (0.09-0.94) 0.039</td>
<td>0.42 (0.12-1.30) 0.081</td>
</tr>
<tr>
<td>R</td>
<td>0.40 (0.01-1.04) 0.049</td>
<td>0.35 (0.01-1.20) 0.086</td>
</tr>
</tbody>
</table>

Multiple theories for C5 palsies are heterogeneous, and in some cases, they are incongruous
• Reperfusion injury of the spinal cord
• Asymmetric injury to the anterior horn cells
• Anterior shift of the spinal cord
• Posterior shift of the spinal cord
• Rotation of the spinal cord
• Nerve root injury
• Tethering of the nerve root
• Parsonage-Turner Syndrome
• Immune mediated brachial plexitis
C5 PALSY RISK FACTORS

- Most studies are retrospective
  - Patient records, administrative datasets
- May not describe objective criteria for diagnosis of C5P
- Most provide only univariate analyses
  - Single factor may show increased risk but association not seen if adjustments for additional factors made
  - Ideally analyses include all major factors input using multivariate regression

C5P RISK FACTORS

- Systemic review using standard methodology
- Prognostic studies with least potential for bias
- Must have one significant ranked factor together with one or more factors evaluated in a multivariate analysis

SIGNIFICANT C5 PALSY RISK FACTORS

- Pre-operative foraminal diameter
- Pre-operative anterior-posterior diameter
- C2-C7 lordosis
- Posterior cord shift
- Pre-operative cord rotation

Joseph R. Dettori, Andrea C. Skelly, Erika D. Brodt

PRE-OPERATIVE FORAMINAL DIAMETER (FD)

- 6 studies reported decreased C5P risk per mm increase in pre-operative FD
- 1 study reported minimal FD significant
PRE-OPERATIVE FORAMINAL DIAMETER

• The odds of C5P almost triples for each mm decrease in pre-op FD (OR 3.05, 95% CI 2.07 to 4.49).

• Posterior approach provided the most consistent and precise estimates showing increased odds of C5P (OR 2.76, 95% CI 1.97 to 3.86).

• Anterior approach estimates did not reach statistical significance and varied substantially across studies.

PRE-OPERATIVE AP DIAMETER

C2-C7 LORDOSIS
**The role of iatrogenic foraminal stenosis from lordotic correction in the development of C5 palsy after posterior laminectomy and fusion**

- Retrospective, 54 consecutive patients, single surgeon
- Laminectomy and instrumented fusion, facet joints decorticated and packed
- 13 C5 palsies (24%)

<table>
<thead>
<tr>
<th>Pre/Post OP</th>
<th>Parameter</th>
<th>No C5 Palsy</th>
<th>C5 Palsy</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>Min C45 FD</td>
<td>3.66 ± 4.87</td>
<td>1.97 ± 0.75</td>
<td>0.05</td>
</tr>
<tr>
<td>Pre</td>
<td>AP diameter</td>
<td>9.58 ± 3.76</td>
<td>7.32 ± 1.67</td>
<td>0.006</td>
</tr>
<tr>
<td>Post</td>
<td>C45 lordosis</td>
<td>−0.09 ± 5.22</td>
<td>2.45 ± 2.77</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**POSTERIOR CORD SHIFT**

- No association
  - 1 good and 1 fair study
- Positive association
  - 2 poor studies

If both APD and MFD were observed to be below the cut-off, the likelihood of post-operative C5 palsy in this sample was 86%.
• 263 patients, retrospective study
• CSP related to posterior cord shift in univariate analysis
  • OR 2.37, 95% CI 1.40 to 4.03
• This was no longer significant in multivariate analysis (P=0.31, effect size not provided)
  • Pre-operative foraminal diameter, age, use of double-door laminoplasty and difference between decompression width and spinal cord width

PRE-OPERATIVE CORD ROTATION

ESKANDER ET AL. J BONE JOINT SURG 2012

• Retrospective review of prospectively collected spine registry data
• 203 patients
• CSP <3/5 by attending

PRE-OPERATIVE CORD ROTATION

TABLE I Relationship Between C5 Palys and Cord Rotation*

<table>
<thead>
<tr>
<th>Cord Rotation</th>
<th>No</th>
<th>Yes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° to 5°</td>
<td>159</td>
<td>0</td>
<td>159</td>
</tr>
<tr>
<td>6° to 10°</td>
<td>5</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>≥11°</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>164</td>
<td>12</td>
<td>176</td>
</tr>
</tbody>
</table>

*The values are given as the number of patients.

APPRAOCH RELATED ISSUES

• Posterior approach (7x CSP of anterior)
  • Less direct anterior decompression
  • Posterior cord shift
  • Lordosis will increase foraminal stenosis
• Anterior approach
  •Generally increase foraminal height
  • No posterior cord shift
  • Direct anterior decompression
  • Remove uncinate processes
DOES A FORAMINOTOMY DECREASE THE RISK OF C5 PALSY?

- **YES**
  - Imaama 2010
  - Katumi 2012
  - Pan 2017
  - Sasai 2003
- **NO**
  - Bydon 2014

- If universally performed, some patients will have no preoperative foraminal stenosis
- Dose dependent
- Increases risk of surgical trauma

C5 PALSY AND INTRAOPERATIVE MONITORING

- **MEPs**
  - Useful
    - Ando 2018
    - Roe 2007
    - Oh 2017
    - Pan 2017
    - Yanase 2010
  - Not useful
    - Shu 2015
    - Tanaka 2006

- **EMG**
  - Useful
    - Ando 2005
  - Not useful
    - Shu 2015

- **EMG AND MEP**
  - Useful
    - Pan 2002

- **SSEP**
  - Not useful
    - Oh 2017
    - Shu 2015

VCT PREOPERATIVE APPROACH TO C5 PALSY

- Evaluate and document arm motility and strength before surgery
  - Active and passive

- Assess the degree of foraminal stenosis
  - Sagittal CT can be useful

- Inform and document the C5P risk discussion with the patient

VCT OPERATIVE APPROACH TO C5 PALSY

- **ANTEROIOR**
  - No monitoring
  - Tape shoulders
  - Microscope
  - Address C45 first
  - Consider oversized graft
    - In moderation
  - Bilateral uncinate resection
    - Visualize both C5 roots
VCT OPERATIVE APPROACH TO C5 PALSY

<table>
<thead>
<tr>
<th>Level</th>
<th>Baseline</th>
<th>After Graft</th>
<th>Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4-5</td>
<td>0.53 ± 0.17</td>
<td>0.63 ± 0.16</td>
<td>18.48</td>
</tr>
<tr>
<td>C5-6</td>
<td>0.48 ± 0.10</td>
<td>0.53 ± 0.13</td>
<td>10.56</td>
</tr>
<tr>
<td>C6-7</td>
<td>0.55 ± 0.16</td>
<td>0.69 ± 0.18</td>
<td>26.12</td>
</tr>
<tr>
<td>overall</td>
<td>0.52 ± 0.14</td>
<td>0.62 ± 0.17</td>
<td>18.39</td>
</tr>
</tbody>
</table>

* Mean ± SD.

VCT IMMEDIATE POSTOPERATIVE APPROACH TO C5 PALSY

C5 palsy after posterior cervical decompression and fusion: cost and quality-of-life implications

Jacob A. Miller, BS1,2,3, Daniel Labelski, BA,1,2,3, Matthew D. Alvi, MRA, MA,1,2,3, Edward C. Botzel, MD1,2,3, Thomas E. Moos, MD1,2,3

VCT DELAYED POSTOPERATIVE APPROACH TO C5 PALSY

• EVALUATE FREQUENTLY
• NERVE TRANSFER
  • MYOCYTE DEATH 18 – 24 MONTHS FOLLOWING DENERVATION
  • AXON GROWTH RATE 1 MM/DAY
  • CONSIDER NERVE TRANSFER 3 – 9 MONTHS POST INJURY
  • EMG AT 6 WEEKS

• 29 PATIENTS
• RECOVERY
  • COMPLETE RECOVERY
    • 4/5 @ 6 WEEKS, 4/5 @ 6 MONTHS
  • PARTIAL RECOVERY
    • 3/5 @ 6 WEEKS, 4/5 @ 6 MONTHS
• EMG @ 6 WEEKS – 6 MONTHS
  • THOSE WHO RECOVERED MORE LIKELY TO HAVE NORMAL MOTOR UNIT (MU) RECRUITMENT
  • COMPLETE RECOVERY PPV 87.5%
  • PRESENCE OF ≥ 2+ FIBRILLATIONS ≤ 6 WEEKS
  • POOR RECOVERY PPV 88.9%
SPONTANEOUS C5 PALSY

- Rare
- 59-year-old man
- Postoperative C5P
- Deltoide 2/5, Biceps 4-/5
- MR/CT/EMG
- Mild right C5 Hypesthesia
- Consider decompression if awake with weakness
- Consider decompression if foraminar stenosis
• CONSIDER MANAGING C5 PALSY AS MANAGING A BASEBALL TEAM.
Emerging Technology in Spine Surgery: Augmented Reality for Enhanced Surgical Navigation

Thomas Noh, MD
Assistant Clinical Professor
John A Burns School of Medicine
Honolulu, HI
Hawaii Community Foundation- Grant
Outline

• Augmented Reality in Spine Surgery
• User Interface
• Future Applications
AR, MR, VR

**Virtual Reality (VR)**
- Fully artificial environment
- Full immersion in virtual environment

**Augmented Reality (AR)**
- Virtual objects overlaid on real-world environment
- The real world enhanced with digital objects

**Mixed Reality (MR)**
- Virtual environment combined with real world
- Interact with both the real world and the virtual environment
**Fig. 1.** Prototype of the intraoperative extended reality visualization system.
Augmented Reality as an Adjunct

• So what exactly does AR add to navigation?
Augmented Reality as an Adjunct

<table>
<thead>
<tr>
<th>Neuronavigation</th>
<th>AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Line of sight</td>
<td>• Integrated line of sight</td>
</tr>
<tr>
<td>• Attention shifting</td>
<td>• No distraction</td>
</tr>
<tr>
<td>• OR Space/Bulky</td>
<td>• Smaller footprint</td>
</tr>
<tr>
<td>• Trainees shift their attention to follow</td>
<td>• Less attention shifting for trainees</td>
</tr>
<tr>
<td>• Thoracolumbar pedicle screw accuracy 90-99% (27-97% freehand)</td>
<td>• ~94-98%</td>
</tr>
</tbody>
</table>
Drawbacks...

### Accuracy
- Relies on surgeon “human factor”
- Unseen movements such as rotation of spine when force is applied
- Imaging errors, tracking device errors, registration errors, inaccurate surgical tools.
- Variable inaccuracy
- Reregistration
- Focal length limitations

### Quality
- Image quality, latency, low brightness or contrast issues
- Software issues
- Visual fatigue
- Headset weight, overheating

### Training
- Steep learning curve for new adapters
- Next generation of surgeons unable to freehand?
Reregistration and Accuracy
Reregistration and Accuracy
AR/MR in Spine Surgery

- Headsup display/side vision
- Pedicle screw placement
- Rod bending
- Minimally invasive pedicle screw placement
- Interbody placement
- Percutaneous vertebroplasty
- Keyhole spine surgery
- Facet joint injections
Future Studies

- Accuracy score that reflects ratio of screw to pedicular size
- Hospital stay, readmission, revision rate, re-operation, $ savings, surgical time
- Rate of accuracy improvement
- Radiation dosing to patient
- Cervical screws, iliac bolts, S2 screws
- Actual time required (setting up system, CT, planning, verification)
- Osteotomies, tumors, deformity correction
Frameless Patient Tracking With Adhesive Optical Skin Markers for Augmented Reality Surgical Navigation in Spine Surgery

Burström, Gustav MD\textsuperscript{a,b}; Nachabe, Rami PhD\textsuperscript{c}; Homan, Robert BSc\textsuperscript{d}; Hoppenbrouwers, Jurgen MSc\textsuperscript{e}; Holthuizen, Ronald MSc\textsuperscript{f}; Persson, Oscar MD, PhD\textsuperscript{a,b}; Edström, Erik MD, PhD\textsuperscript{a,b}; Elmi-Terander, Adna MD, PhD\textsuperscript{a,b}

Author Information

SPIE: November 15, 2020 - Volume 45 - Issue 22 - p 1598-1604
doi: 10.1097/BRS.0000000000003628
THANK YOU!

Noh Lab
- Scott Lozanoff, PhD
- Gina Watanabe, BS
- Dao McGill
- Jessee Thompson, MS

Hawaii Pacific Health
- Les Chun, MD
- Russell Woo, MD

JABSOM
- Kenric Muraayama, MD
- Takashi Matsui, MD, PhD

Brigham and Women’s Hospital
- Parikshit Juvekar, MD
- Alex Golby, MD
- Steve Piper

ThomasNohMD
noht@hawaii.edu


Training

• Freehand/AR-guided, Contiguous/Spread
• (MS1, MS4, Intern, Senior resident)
• Freehand Group 1: Train wkly x7 wks
• Freehand Group 2: Daily x7 days
• AR Group 3: Weekly x7 wks
• AR Group 4: Daily x 7 days
• TEST DAY: Compare all groups in a test scenario where AR fails and need to freehand
ANTERIOR COLUMN APPROACHES

Vedat Deviren, MD
Professor of Orthopaedic Surgery
University of California, San Francisco

ANTERIOR APPROACH BENEFITS

Within the past 15 years, multiple anterolateral approaches to the spine have become widely adopted. These approaches allow wide exposure of the disc space for:

• Large interbody graft
• Shorter operative times
• Less blood loss
• Indirect decompression of neurological tissue

GOAL = Decompression, Stabilization & Alignment
LUMBAR INTERBODY FUSION

Four of the most widely used procedures include:
A. (ALIF) anterior lumbar interbody fusion
B. (LLIF) “transpsoas” lateral lumbar interbody fusion
C. (OLIF) “anterior to the psoas” oblique lumbar interbody fusion
D. (PTP) “new transpsoas” prone transpsoas

LUMBAR INTERBODY FUSION

The primary surgical goal of all four procedures is to implant the largest possible interbody graft to:
• facilitate fusion rates
• maximize segmental lordosis
• provide indirect neural decompression
  • by expansion of the bony neuroforamen
  • distraction of ligamentous stenosis of the central canal
VASCULAR & VISCERAL ANATOMY

- Abdominal aorta
- Segmental arteries
- Iliac arteries
- Iliac veins
- Vena cava
- Bowel
- Kidney

REVIEW & DISCUSS: VASCULAR ANOMOLIES

Lateral position of iliac vessels

Potential vascular injury during contralateral annular release

Cobb Elevator L4-L5
TRANSITIONAL ANATOMY

Normal vs. Transitional

Extensive preoperative imaging is critical for optimal LLIF surgical planning. Axial MRI or computed tomography (CT) is necessary to ensure that intra-abdominal blood vessels are not vulnerable to injury in the path of lateral access and discectomy.

ALIF ADVANTAGES

• No disruption of posterior structures
• No nerve root retraction necessary
• Large structural spacer possible, with large graft area for fusion and alignment correction
• Can be performed open, mini-open, or laparoscopically (although no longer common)
ALIF DISADVANTAGES

• Vascular injury risk; requires expertise of access surgeon for approach
  
• Retrograde ejaculation

• Usually requires stabilization with internal fixation instrumentation due to ALL disruption
  
• Relies on indirect decompression

LLIF ADVANTAGES

• Minimally invasive (minimal blood loss and quick patient recovery)

• Avoids the risks of posterior (cauda equina) and anterior (vascular) approaches

• Inherently stable construct that is ligament-sparing with the ability to place a large graft on the apophyseal ring

• Ability to achieve great disc height restoration, providing indirect decompression of nerves and deformity alignment
LLIF DISADVANTAGES

- Plexus, bowel, vascular injury
- Inability to address L5-S1
  - Relies on indirect decompression
- Requires reposition to prone for other posterior procedures
- Not familiar to all surgeons; requires additional training

OLIF ADVANTAGES

- MIS & biomechanical advantages of LLIF
- Doesn’t dissect or traverse the psoas muscle
- Neuromonitoring is not required*
- Can access L5-S1
OLIF DISADVANTAGES

- Sympathetic chain, bowel, vascular injury
- Contralateral foramen violation
- Relies on indirect decompression
- Requires reposition to prone for other posterior procedures
- Not familiar to all surgeons; requires additional training

PTP ADVANTAGES

- MIS & biomechanical benefits of LLIF plus….
- Better sagittal alignment
- More forgiving plexus position
- Ability to address posterior column w/o flip
- “Familiarity of prone”
PTP DISADVANTAGES

- Plexus, bowel, vascular injury
- Inability to address L5-S1
  - Learning curve
- Difficulty with morbidly obese

PTP CASE EXAMPLE

PATIENT BACKGROUND:

- 74yo f with predominantly back pain and difficulty standing upright.
- Pain for past 4-5 years.
- Takes hydrocodone daily for pain
- DEXA: Osteopenia
- No PMH
PTP CASE EXAMPLE

Stage 1: • L4/S1 ALIF

Stage 2: • L2/4 PTP • T4-Pelvis Posterior Spinal Fusion • L1-S1 Type 1 Osteotomies

PLAN

PTP CASE EXAMPLE

17

18
PTP CASE EXAMPLE

ALIGNMENT PLAN

<table>
<thead>
<tr>
<th>SPINOCEVICAL PARAMETERS</th>
<th>PRE-OP</th>
<th>PLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvic Tilt, PT (°)</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Pelvic Incidence, VA (°)</td>
<td>33</td>
<td>58</td>
</tr>
<tr>
<td>Sacral Slope, SS (°)</td>
<td>38</td>
<td>46</td>
</tr>
<tr>
<td>Lumbar Lordosis, LL (°)</td>
<td>-42</td>
<td>-58</td>
</tr>
<tr>
<td>Pi-Ll (°)</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>TI Pelvic Angle, TPA (°)</td>
<td>22</td>
<td>8</td>
</tr>
<tr>
<td>Sagittal Vertical Axis, DVA (mm)</td>
<td>52</td>
<td>4</td>
</tr>
<tr>
<td>T4-T12 Thoracic Kyphosis, TK (°)</td>
<td>41</td>
<td>31</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SEGMENT DISTANCE (mm)</th>
<th>PRE-OP</th>
<th>PLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle (°)</td>
<td>-47</td>
<td>-47</td>
</tr>
<tr>
<td>Apex</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Apex Distance to C7 PL (mm)</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Apex Distance to C2 PL (mm)</td>
<td>56</td>
<td>58</td>
</tr>
<tr>
<td>Kyphol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle (°)</td>
<td>61</td>
<td>61</td>
</tr>
<tr>
<td>Apex</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Apex Distance to C7 PL (mm)</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td>Apex Distance to C2 PL (mm)</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>Lordol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle (°)</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>Apex</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Apex Distance to C7 PL (mm)</td>
<td>-68</td>
<td>-68</td>
</tr>
<tr>
<td>Apex Distance to C2 PL (mm)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

PTP CASE EXAMPLE

STAGE 1
PTP CASE EXAMPLE

INTRA-OP STAGE 2

PTP CASE EXAMPLE

POST-OP
COMPLICATIONS

Transient thigh numbness and hip flexion weakness likely due to retraction of the psoas muscle and associated sensory nerves:

- Hynes encountered thigh numbness in 16% and weakness of the hips and quads in 6.5%
- Silvestre et al. reported a 2.2% incidence of transient incisional pain and 1.7% incidence of lower-extremity sympathetic chain disruption symptoms after OLIF
- Fujibayashi et al. reported that 7.1% of patients experienced transient leg weakness and 21.4% experienced transient numbness
- DiGiorgio et al. reported a 6.1% incidence of transient leg weakness and 21.4% experienced transient numbness

Vascular injury, mainly involving venous structures anterior to the psoas at a rate similar to that for ALIF:

- Hynes reported a vascular injury rate of 1.1% in 186 patients
- Silvestre et al. reported a venous injury rate of 1.7% in 176 patients
- Ohtori et al. reported a 2.8% incidence of segmental artery injury in their 35-patient cohort

Other infrequently reported complications include injury to the sympathetic trunk, resulting in temperature discrepancies to the lower extremities, and postoperative ileus

PTP, similar to lateral (not enough data)

KEY POINTS

- **ALIF, LLIF, and OLIF** are powerful techniques to achieve spinal arthrodesis by delivering larger interbody grafts
- **ALIF** - safest at the L5–S1 interspace but the risk of vascular injury increases when targeting proximal lumbar segments
- **LLIF** - requires neuromonitoring to ensure safe traversal of the psoas muscle and positioning of the retractor with respect to the lumbar plexus
- **OLIF** - does not require neuromonitoring because of its pre-psoas approach, but the technique appears to have a higher risk of vascular injury, and long-term fusion and subsidence rates have not been reported
- **PTP** - better sagittal correction, single position, familiar position, wider window of access through psoas
CONCLUSIONS

• ALIF, LLIF, PTP and OLIF have unique surgical applications, executions, and associated complications
• All 4 procedures have similarly high fusion rates
• The optimal approach depends heavily on the individual structural constraints of the pathology, the anatomy of the individual patient, and the familiarity of the surgeon with available options
FUSION LEVELS FOR ADOLESCENT IDIOPATHIC SCOLIOSIS

Pediatric Neurosurgeon, Division of Pediatric Neurosurgery, Phoenix Children’s Hospital
Associate Director, Comprehensive Pediatric Spine Center, Phoenix Children’s Hospital
Consultant, Department of Neurological Surgery, Mayo Clinic Arizona
Assistant Professor, Mayo Clinic Alix School of Medicine
Director of International Practice, Mayo Clinic Arizona

Disclosures

- Presenter: Jamal McClendon Jr., MD
  - d (SeaSpine – minor [<$5,000])
  - e (No conflicts of interest relevant to this talk)
NATURAL HISTORY
• Adolescent idiopathic scoliosis

• Natural History
  • 194 patients treated for AIS with f/u of 31-51 years
    • Thoracic curves >50° will likely progress
  • 102 patients with untreated AIS, 31-53 year f/u
    • Thoracic curves >50° progress most rapidly (0.75-1% per year)


ADOLESCENT IDIOPATHIC SCLIOsis

Prevalence of surgically treated curves

1AN  19%
1BN  11%
2AN  10%
5CN  10%
1CN  8%

CHOOSING SURGICAL LEVELS

• Primary Goals
  - Halt curve progression
  - Prevent cardiopulmonary compromise for Cobb > 100°
  - Prevent decompensation
  - Maintain coronal/sagittal alignment
  - Fuse least number of motion segments
  - Avoid complications

• Secondary Goals
  - Improve cosmesis/deformity
  - Balance shoulders and level pelvis

Lenke LG, Edwards CC, Bridwell KH. Spine 2003; 28:S199-S207

Balancing Ideas for Treatment

• Selective fusion
  
• Non-selective fusion
CONTROVERSY

1. When to fuse
2. Time to fuse once decision is made
3. FUSION LEVELS
4. Constructs (all screws, hooks, wires, bands, hybrid)
5. Correction (in situ, apical translation, derotation)
6. Implant density
7. Soft landing
8. Anterior versus posterior

DECISION MAKING FOR LENKE 1

• Do we fuse the non-structural lumbar curve?
• Will there be spontaneous correction?
• Can we estimate the amount of lumbar correction?
• How do we predict lumbar decompensation?
• Lumbar curve will spontaneous correct with MT fusion
• No difference in SLCC between ASF or PSF
• PSF (↑EBL, ↑transfusions, ↑constructs, ↓OR time, p<0.01)
• ASF (↑stay, ↑chest tube, p<0.01)
• Larger 1A and 1B curves use more resources

DECISION MAKING FOR LENKE 3 AND 4 CURVES

• Do we fuse the structural lumbar curve?
  • If not, how much correction will there be of lumbar curve?
• Can we predict lumbar decompensation?
15 YO FEMALE WITH LENKE 3CN AIS

• T4-T12 PSF with PCOs

Selective thoracic fusion
Goal to spare motion segments
Less surgical time
Risk of residual deformity and decompensation over time
Possible spinal imbalance

UPPER INSTRUMENTED VERTEBRA

1. PT structural (yes/no)
2. Shoulder balance preoperatively (L↑, N, R↑)
3. Planned correction of MT

T2, T3, or T4
<table>
<thead>
<tr>
<th>T2</th>
<th>T3</th>
<th>T4/T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>High left shoulder</td>
<td>Level shoulders</td>
<td>High right shoulder</td>
</tr>
<tr>
<td>PT structural</td>
<td>PT ? Structural</td>
<td>PT non structural</td>
</tr>
<tr>
<td>Kyphosis in upper thoracic</td>
<td>Mild kyphosis in upper thoracic</td>
<td>No kyphosis in upper thoracic</td>
</tr>
<tr>
<td>Planned significant correction of MT</td>
<td>Planned significant correction of MT</td>
<td></td>
</tr>
</tbody>
</table>

**LOWER INSTRUMENTED VERTEBRA**

- King-Moe (Stable vertebra)
- Cotrel-Dubousset (Disc reversal)
- Lenke (Last touched)

**Classification**

- **SRS 3D classification**
COMMON LENKE 1,2,3,4 RULES

• Distal fusion to LTV or SV minus 1
  • except within 1.5 levels of lumbar apex with rotation or skeletal immature
• ATR > 1.2 can consider thoracic only fusion
• Might need to go to SV if high LIV tilt


LOWER INSTRUMENTED VERTEBRA

<table>
<thead>
<tr>
<th>L3</th>
<th>L4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave disc L3-4</td>
<td></td>
</tr>
<tr>
<td>Parallel disc L3-4</td>
<td></td>
</tr>
<tr>
<td>Convex disc L3-4</td>
<td></td>
</tr>
</tbody>
</table>

Disclaimer: I usually break rules to stop at L3
Complication rate for AIS

• Overall complication rate for AIS is 6.3 %
Minimizing Complications / Achieve Desired Outcome

• Identifying goals of an operation
• Clinical pathways
• Reducing intraoperative and postoperative blood loss
• Shorten anesthetic duration
• Postoperative pain management

THANK YOU
Choosing Your Osteotomy in Posterior Deformity Correction

Alexander Tuchman, MD
Assistant Professor, Cedars-Sinai Department of Neurosurgery
UCSF Pediatric and Adult Spine Surgery Course, 7/13/2022-7/16/2022

disclosures

- None
PCO vs. 3CO

- **Posterior Column Osteotomies (PCO)**
  - Ponte, Smith Peterson
  - Type II

- **Three Column Osteotomies (3CO)**
  - Pedicle subtraction, extended pedicle subtraction, Vertebrectomy resection
  - Type III, IV, V, VI

### Posterior Column Osteotomies (PCO)

- **Posterior Column Osteotomies (PCO)**
  - Posterior shortening procedure
  - Generally produces about 10° of sagittal plane correction
  - Involve total facet resection, ligamentum flavum resection, inferior laminectomy
    - Smith-Peterson\(^1\)
      - Original description in 1945 for correction of flexion deformities in RA and AS
      - Disrupts the ALL → lengthening of anterior column and shortening of posterior column
    - Ponte\(^2\)
      - Correction is through the unfused disc space and ALL is left intact

---

Posterior Column Osteotomies (PCO)

- **Effective**
  - Thoracic PCO increased ROM
    - Flexion-extension: 33%, 56%, 69% for 1-, 2-, or 3-level
    - Axial Rotation: 16%, 28%, and 65%
  - Multilevel PCO can achieve similar correction to 3CO
  - Improved correction of scoliosis compared to inferior facetectomies
  - Increased loosening effect on periapical segments

- **Safe**
  - AIS: 0.37% neurologic complication rate with PCO, 0.17% without PCO
  - Increased blood loss and operative time
    - But significantly less than 3CO

Three Column Osteotomy (3CO)

- All three columns of the spine are destabilized
  - Temporary fixation is necessary
  - Able to correct through rigid or fused deformities
  - About 30° correction with a PSO more with a VCR

- Pedicle subtraction osteotomy (PSO) (type 3)
- Extended Pedicle subtraction osteotomy (type 4)
- Vertebrectomy Column Resection (VCR) (type 5)
- Multilevel Vertebral Column Resection (type 6)
Three Column Osteotomy (3CO)

- **Blood loss**
  - 642-2984 mL average EBL for PSO
  - 500-6880 mL average EBL for VCR

- **Neurologic Injury**
  - New neurologic deficit rates after 3CO reported between 8.6%–40.3%²⁻⁶
  - Scoli-Risk-1 (75% 3CO) → 22.18% neurologic decline from baseline at discharge⁷

- **Pseudoarthrosis**
  - 10% pseudoarthrosis rate for PSOs⁸
  - Up to 27% implant failure⁹
    - Improved with supplemental rods¹⁰

---

Factors Affecting Decision Making Between

- **Anatomic Considerations**
  - **Flexibility**
  - **Bone Quality**

- **Alignment Considerations**
  - Deformity Angular Ratio
  - Location of the deformity and restoration of spinal shape

- **Patient Specific Considerations**
  - Age
  - Medical Comorbidities (frailty)

---

Flexibility

- Supine XR or Scout Views from CT
  - Flexible
    - Significant correction of the deformity with dynamic imaging
  - Rigid
    - Ankylosed spine but still some correction through open disc spaces
  - Fused
    - Typically requires a 3CO

Factors Affecting Decision Making Between

- Anatomic Considerations
  - Flexibility
    - Bone Quality
  - Alignment Considerations
    - Deformity Angular Ratio
    - Location of the deformity and restoration of spinal shape
  - Patient Specific Considerations
    - Age
    - Medical Comorbidities (frailty)
Bone Quality

- Preoperative DXA
  - Hip and/or wrist
- Elliptical ROI
  - Limited by heterogeneity of threshold value to diagnose osteoporosis/osteopenia
  - HU < 135 has been proposed as a reasonable threshold
- Stronger bone → better fixation → more force can be transmitted to the spine to get correction


Bone Quality (What can we do about it)

- Anabolic agents
  - Teriparatide
    - fully active (1-34) amino acid sequence of human parathyroid hormone (PTH)
  - Aboloparatide
    - a synthetic analog of parathyroid hormone-related peptide (PTHrP)
- Increased insertional torque for pedicle screws in patients treated with at least 1 month of Teriparatide preoperatively.

11

12

Bone Quality (What can we do about it)

- Anabolic agents
  - Teriparatide
    - fully active (1-34) amino acid sequence of human parathyroid hormone (PTH)
  - Abloparatide
    - a synthetic analog of parathyroid hormone-related peptide (PTHrP)

- Postoperative Teriparatide reduced pedicle screw loosening for 1-2 level fusions in osteoporotic women.
  - 7-13% with Teriparatide
  - 13-26% with risedronate
  - 15-25% in controls


Mean 2 months of preoperative Teriparatide continued 8 months postop had fusion rate of 82% in Teriparatide vs 68% in risedronate.

Factors Affecting Decision Making Between

- Anatomic Considerations
  - Flexibility
  - Bone Quality

- Alignment Considerations
  - Deformity Angular Ratio
    - Location of the deformity and restoration of spinal shape

- Patient Specific Considerations
  - Age
  - Medical Comorbidities (frailty)

Deformity Angular Ratio (DAR)

- DAR = Cobb angle divided by the number of vertebrae involved in the curve
- Total-DAR = Coronal-DAR + Sagittal-DAR
  - T-DAR > 25
  - S-DAR > 15
  - Increased risk for intraoperative SCM events and new postoperative neurologic deficits in patients undergoing vertebral column resection
  - Also helpful to determine type of osteotomy
    - Short angular curve → 3CO
    - Long sweeping curve → multiple PCOs

Factors Affecting Decision Making Between

- Anatomic Considerations
  - Flexibility
  - Bone Quality

- Alignment Considerations
  - Deformity Angular Ratio
  - Location of the deformity and restoration of spinal shape

- Patient Specific Considerations
  - Age
  - Medical Comorbidities (frailty)

Spinal Shape

![Classification of normal sagittal spine alignment: refounding the Roussouly classification](image-url)
Spinal Shape

• Failure to restore normal shape according to Roussouly Classification → mechanical complication RR 3 (CI 1.5–4.3; p < 0.001)

• 13.5% PJK when postoperative sagittal apex of the lumbar curve was identical to the theoretical apex
• 41.4% PJK in cases where the theoretical and actual apex were different

75 yo woman with medical comorbidities, presenting with myelopathy from a thoracic disc and severe back pain

- Does spinal shape correlate with functional outcome?
- Is it worth the increased risk of 3CO if that is the only way to restore spinal shape?
- Is spinal shape as important when the fusion is extended to the upper thoracic spine?

Roussouly type II with post op apex of kyphosis at L2-3 and doing very well at 2 years

T12-L3 & L5-S1 PCOs

SVA: 13 cm → 1.5
PI: 45°
LL: 0° → 43°
PT: 32° → 14°
Factors Affecting Decision Making Between

- **Anatomic Considerations**
  - Flexibility
  - Bone Quality

- **Alignment Considerations**
  - Deformity Angular Ratio
  - Location of the deformity and restoration of spinal shape

- **Patient Specific Considerations**
  - Age
  - Medical Comorbidities (frailty)

---

Age Adjusted

- Sagittal spinopelvic alignment varies with age

- Operative realignment targets should account for age
  - Younger patients require more rigorous alignment objectives.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>% in Database</th>
<th>Mean Age in Database</th>
<th>ODI US-Norm*</th>
<th>PT</th>
<th>PI–LL</th>
<th>LL–TK</th>
<th>SVA</th>
<th>TPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;35</td>
<td>17.7</td>
<td>26.2</td>
<td>9.49</td>
<td>11.1</td>
<td>–11.3</td>
<td>29.2</td>
<td>–29.1</td>
<td>4.4</td>
</tr>
<tr>
<td>35–44</td>
<td>8.8</td>
<td>40.7</td>
<td>11.77</td>
<td>15.5</td>
<td>–6.2</td>
<td>21.9</td>
<td>–4.0</td>
<td>10.0</td>
</tr>
<tr>
<td>45–54</td>
<td>19.9</td>
<td>51.2</td>
<td>15.41</td>
<td>18.9</td>
<td>1.7</td>
<td>16.4</td>
<td>16.5</td>
<td>14.5</td>
</tr>
<tr>
<td>55–64</td>
<td>28.0</td>
<td>60.5</td>
<td>20.87</td>
<td>22.1</td>
<td>3.3</td>
<td>11.1</td>
<td>37.0</td>
<td>18.8</td>
</tr>
<tr>
<td>65–74</td>
<td>19.5</td>
<td>69.7</td>
<td>24.62</td>
<td>25.2</td>
<td>7.5</td>
<td>6.1</td>
<td>55.6</td>
<td>22.8</td>
</tr>
<tr>
<td>≥74</td>
<td>6.2</td>
<td>79.6</td>
<td>32.54</td>
<td>28.8</td>
<td>13.7</td>
<td>0.2</td>
<td>79.9</td>
<td>27.8</td>
</tr>
</tbody>
</table>

*value extrapolated using the PCS US-norm.

---

Age Adjusted Normative Sagittal Alignment Values

- Sagittal spine-pelvic alignment varies with age
- Operative realignment targets should account for age
  - Younger patients require more rigorous alignment objectives.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Moderate Disability (ODI = 20)</th>
<th>Severe Disability (ODI = 40)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PT</td>
<td>PI–LL</td>
</tr>
<tr>
<td>&lt;35</td>
<td>11.3</td>
<td>–6.8</td>
</tr>
<tr>
<td>35–44</td>
<td>15.1</td>
<td>–2.7</td>
</tr>
<tr>
<td>45–54</td>
<td>17.8</td>
<td>0.2</td>
</tr>
<tr>
<td>55–64</td>
<td>20.2</td>
<td>2.9</td>
</tr>
<tr>
<td>65–74</td>
<td>22.6</td>
<td>5.5</td>
</tr>
<tr>
<td>≥75</td>
<td>25.2</td>
<td>8.3</td>
</tr>
</tbody>
</table>


Factors Affecting Decision Making Between

- Anatomic Considerations
  - Flexibility
  - Bone Quality
- Alignment Considerations
  - Deformity Angular Ratio
  - Location of the deformity and restoration of spinal shape
- Patient Specific Considerations
  - Age
  - Medical Comorbidities (frailty)
Adult Spinal Deformity Frailty Index (ASD-FI)

- ASD-FI is a component of preoperative risk stratification
- Health deficits documented by the physician
- Patient reported questions
- Frailty is strongly associated with risk of complications after surgery
- Invasiveness of surgery may be modified based on pre-operative risk stratification

Factors Affecting Decision Making Between

- Anatomic Considerations
  - Flexibility
  - Bone Quality
- Alignment Considerations
  - Deformity Angular Ratio
  - Location of the deformity and restoration of spinal shape
- Patient Specific Considerations
  - Age
  - Medical Comorbidities (frailty)
Thanks!
PROXIMAL JUNCTIONAL KYPHOSIS

Etiology, Risk Factors & Prevention
(Pediatric Focus)

Emmanuel Menga, M.D., FAAOS, FSRS
Associate Professor of Orthopaedics & Neurosurgery
Associate Program Director, Orthopaedic Residency
Louis A. Goldstein Spine Fellowship Director

Department of Orthopaedic Surgery
University of Rochester School of Medicine and Dentistry
Rochester, NY

Disclosure

• Evolution Spine (Consultant, Royalties)
• Globus Medical (Consultant)
Proximal Junctional Kyphosis

- DEFINE Proximal Junctional Kyphosis (PJK)
- EPIDEMIOLOGY
- CLASSIFICATION
- ETIOLOGY - RISK FACTORS
- OUTCOMES
- CURRENT CONCEPTS - PREVENTION

June 2017 - 10 y/o premenarchal, LPT 53/RTL 70, Risser 0. Hyperkyphosis.
- Surgery T3-L4

Feb 2018 – c/o neck pain and noticeable worsening PJK


Proximal Junctional Kyphosis

- First described in 1994
- Correction > 50% kyphosis of Scheuermann’s Disease
- Cotrel-Dubousset instrumentation

Proximal junctional sagittal cobb angle ≥ 10° or proximal junctional sagittal cobb angle at least 10° greater than the preoperative measurement.

Glattes et al. Spine 2005
Proximal Junctional Kyphosis

- Bridwell et al. investigated $\geq 20^\circ$ as the critical angle (ASD)
- Helgeson et al. proposed $>15^\circ$ as the new critical angle

Severe cases of PJK (symptomatic)

- Proximal Junctional failure (PJF)
- Topping-off syndrome
- Proximal junctional acute collapse
EPIDEMIOLOGY

- PJK $\geq 10^\circ$. Prevalence 9.2-46% Adolescent Idiopathic Scoliosis
- PJK $\geq 10^\circ$. Prevalence 20-39% Adult spinal deformity.
- PJK $\geq 20^\circ$. Bridwell et al. Prevalence of 27.8% ADS at 3.5yrs
- PJK $\geq 15^\circ$. Helgeson et al. Prevalence 5-8.2% AIS at 2yrs.
- Lonner et al. Incidence 30-32% in patients with scheuermann kyphosis

Timing of PJK development

- Most commonly occur within 2 years of surgery
- 43% Idiopathic scoliosis (50% Peds/ 50% Adult) developed PJK within the first year of surgery
- 59% of the total PJK angle occurred within 8 weeks of surgery in Adult spinal deformity
- 76% of PJK occurred within 3 months after surgery & accounted for 53% total PJK angle after Adult spinal surgery

Mode & Location of failure

- Upper thoracic (above T7) UIV: Soft tissue failure (34%) (p = 0.02)
- Proximal thoracic (T2-5) UIV: Subluxation
- Thoracolumbar (T7 to L1-2) Fracture (66%) (p = 0.00)
- Distal Thoracic (T9-11) UIV: Compression fracture

CLASSIFICATION

Grading and type of PJK

- Grade A: increase angle 10-14°
- Grade B: increase angle 15-19°
- Grade C: increase angle ≥ 20°

- Type 1: PJK from disc & ligamentous failure
- Type 2: Bone failure
- Type 3: Implant/bone interface failure
RISK FACTORS

Univariate analysis:

- Age >55
- BMI (mean 25)
- BMD (Osteopenia/Osteoporosis)
- Male sex
- Thoracoplasty
- Magnitude of TK curve correction (>40°)
- Pedicle screw fixation at UIV
- PSF
- LIV at Sacrum
- Incomplete restoration of LL
- GSA = TK + LL + PI > 45°

RISK FACTORS

Multivariate analysis:

- Low risser grade
- UIV T1-3
- Combined Anterior/Posterior surgery
- Over correction of SSVL
RISK FACTORS

- Patient specific risk factors
- Surgical risk factors
- Radiographic risk factors (restoration of sagittal plane alignment)
- Relative risk of the various risk factors are not well understood

Patient Specific Risk Factors

- Gender (male>female)
- Age
- BMI
- Osteopenia/Osteoporosis
- Sarcopenia
- Alcohol
- Cigarette smoking
- Curve flexibility (TK)
### Surgical Risk Factors

- Type of instrumentation
- Anterior/Posterior instrumentation
- Proximal instrumentation level (UIV)
- Pelvic fixation (LIV)
- Integrity of the posterior ligamentous complex

### Radiographic risk factors

*Restoration of Sagittal Plane Alignment*

*Conic of Economy*
Current literature largely based on Schwab criteria/sagittal modifiers

- C7 Plumbline
- Thoracic Kyphosis (TK)
- Lumbar Lordosis (LL)
- Pelvic incidence (PI)
- Sagittal Vertical Axis (SVA)

Radiographic risk factors
Restoration of Sagittal Plane Alignment

Prevention

- Fixation techniques (UIV)
- Global sagittal alignment
- Osteopenia/Osteoporosis
Prevention

Fixation techniques (UIV)

- Pedicle Screw
- Hooks
- Tethers
- Vertebroplasty

Pedicle screw fixation: Rigid fixation with benefit of higher fusion rates

Rigid fixation at UIV: Underlying risk factor for PJK/PJF

Disruption of Posterior ligamentous complex (posterior tension band)
**Prevention**

**Fixation techniques (UIV)**

- Minimize disruption of posterior tension band

1. Meticulous dissection at the UIV
2. Maintain Interspinous ligament & fascia, facet capsule at UIV
3. Exposure limited to screw entry point

---

**Prevention**

**Instrumentation**

**Fixation techniques (UIV)**

Reduce loading at the UIV

- Gradual transition to the mobile segments above the UIV: **Hooks**
Prevention

Fixation techniques: Hooks at UIV

- **Kim et al, Spine ’07**: Hooks only 22% vs hybrid 29% vs All pedicle screws 37%.

- **Helgeson et al, Spine ’10**: Pedicle screws (37pts) vs hooks (51pts) vs hybrid (177pts) vs pedicle screws with hooks only at UIV (18pts):
  1. **Averg angle**: PJK at 2yrs 8.2° (-1 to 18) all screw construct stat sig vs 5.7° hybrid (p = 0.02) & 5° all hook construct (p = 0.014)
  2. 15° critical angle, Incidence of PJK: 0% all hooks, 2.5% hybrid, 8.1% pedicle screw & 5.6% pedicle screws with hooks at UIV construct

- **Hassanzadeh et al, ’13**: hooks at UIV vs screws at UIV. No PJK in hook group and 30% (8/27) in screw group developed PJK at 2 year followup

---

Current Concepts

Tethers

Fixation techniques (UIV)

Reduce loading at the UIV

- Gradual transition to the mobile segments above the UIV: Tethers

*Buell et al. Operative Neurosurgery 2019*
Proximal segment ROM
1. ROM PS: 16% UIV – 1 to 91% at UIV
2. ROM TPH: 27% UIV – 1 to 92% at UIV
3. ROM Tether:
   a) TE-UIV+1: 14% of intact model UIV-1, 76% at UIV & 98% at UIV + 1
   b) TE-UIV+2: 10% at UIV-1, 51% at UIV & 69% at UIV + 1 & 97% at UIV +2
   c) TE-UIV+3: 7% at UIV-1, 33% at UIV & 45% at UIV + 1 & 64% at UIV +2

Proximal segment intradiscal pressures, pedicle screw loads & ligament forces in the PLC progressively reduced with increasing number of posterior tethers.
**Prevention**

**Fixation techniques: Tethers at UIV**

- **Buell et al, Operative Neurosurgery ’19**: 3month followup. Non tether 45% vs tether/spinous process 34% vs tether/crosslink 17%. 3month followup (Tether vs non tether \(p = .011\))

- **Buell et al, World Neurosurg ’19**: 1 yr followup. PSF lower thoracic UIV (T9-11) junctional tether protective against PJK

- **Zaghloul et al, Orthopaedics ’16**: 11 month followup. 0% PJK in 18pts tether

**Vertebroplasty**

**Fixation techniques (UIV):**

Extend the loading to UIV+ 1 (vertebroplasty)

- **Kebaish et al. Spine Deformity 2013**: low incidence of PJK 8%/PJF 5% @ 2yrs

- **Gjolaj et al. The Spine Journal 2017**: PJK 36% Control vs 23% vertebroplasty (\(p = .020\) @ 2yrs)

- **Kebaish et al. The Spine Journal 2017**: PJK 8%/PJF 5% @ 2yrs \(\rightarrow\) 28% PJK @ 5yrs
Prevention

Global sagittal alignment

Cone of Economy

Schwab et al. Spine 2006
Current literature largely based on Schwab criteria/sagittal modifiers

- C7 Plumbline
- Thoracic Kyphosis (TK)
- Lumbar Lordosis (LL)
- Pelvic incidence (PI)
- Sagittal Vertical Axis (SVA)
- Global Sagittal Alignment

Hostin et al. '13

Restoration of Global sagittal alignment

(GSA = TK + LL + PI ≤ 45°) (84% PJK with non-ideal GSA)

- Magnitude of thoracic kyphosis (TK)
  (Preop TK ≥ 40° & post op decrease <5°)

- Overcorrection of SVA >50mm pre→post associated with PJK

Yagi et al. Spine 2011
**Restoration of Sagittal Plane Alignment**

- Age based normative sagittal alignment in asymptomatic adult spine

- Increasing age correlated with increase
  1. C7 SVA
  2. T1PA
  3. GSA
  4. KFA (Knee flexion angle)
  5. PI-LL (due to decreasing LL with age)

*Iyer et al. Spine 2016*

---

**Restoration of Sagittal Plane Alignment**

- Increase rate of mechanical failure including PJK and revision despite restoration of Spinopelvic parameters as described by Schwab

- “*Patient specific*” normal & pathologic alignment remains unknown

- Need for new methods of analyzing and planning to avoid manageable complications

- Generally agreed spinopelvic alignment parameters should be viewed relative to each other

- PI is the only “*relatively constant*” parameters
**Pelvic-incidence-based** proportional tool to predict mechanical complications (PJK & PJF)

- PI is a continuum (PI range 27° -90°)
- Standardized sagittal parameters (eg. PT, SVA) might not always be pathologic
- Distribution of lordosis not considered in Schwab criteria

Yiglor et. Global Alignment & Proportion (GAP) Score. JBJS 2017

---

**Restoration of Sagittal Plane Alignment**

- Develop & validate scoring system on global alignment in relation to the PI to predict mechanical complications for adult spinal deformity.

**Hypothesis:** GAP score would better assist with analysis and planning of treatment *tailored to each individual*

**Design:** Multicenter, Retrospective/prospective study, ≥ 2yr fu, ≥ 4 levels PSF, ≥ 18 + 1 criteria (coronal cobb ≥ 20°, SVA ≥ 5cm, PT ≥ 25°, TK ≥ 60°

**Gap score:** relative pelvic version, relative LL, LL distribution index, relative spinopelvic alignment and age factor. *(0 to 13 points)*

Yiglor et. Global Alignment & Proportion (GAP) Score. JBJS 2017
**Restoration of Sagittal Plane Alignment**

- 43% (32/74) Mechanical complication (11% PJK & 15% PJF) with 23% revision rate for overall mechanical complication.

Mechanical complication rate:
1. 6% for patients with proportioned spinopelvic state according to GAP
2. 47% rate for patients with moderately disproportioned spinopelvic state according to GAP
3. 95% rate for patients with severely disproportioned spinopelvic state according to GAP

-Yiglor et. Global Alignment & Proportion (GAP) Score. JBJS 2017

**Restoration of Sagittal Plane Alignment**

- HRQOL Measures

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0Dl</td>
<td>21.3 ± 13.4</td>
<td>35.1 ± 17.9</td>
<td>38.3 ± 19.9</td>
<td>F(1,70) = 11.496, p = 0.001</td>
</tr>
<tr>
<td>COMI</td>
<td>3.1 ± 2.0</td>
<td>4.2 ± 2.1</td>
<td>4.8 ± 2.8</td>
<td>F(1,82) = 6.169, p = 0.016</td>
</tr>
<tr>
<td>SRS-22 subtotal</td>
<td>3.7 ± 0.6</td>
<td>3.2 ± 0.7</td>
<td>3.3 ± 0.8</td>
<td>F(1,70) = 4.392, p = 0.040</td>
</tr>
<tr>
<td>SF-36 PCS</td>
<td>43.2 ± 7.7</td>
<td>38.5 ± 9.3</td>
<td>37.9 ± 8.8</td>
<td>F(1,70) = 5.689, p = 0.020</td>
</tr>
<tr>
<td>SF-36 MCS</td>
<td>49.1 ± 8.5</td>
<td>42.4 ± 9.3</td>
<td>44.3 ± 12.9</td>
<td>F(1,70) = 3.326, p = 0.072</td>
</tr>
</tbody>
</table>

-Yiglor et. Global Alignment & Proportion (GAP) Score. JBJS 2017
Prevention

- Small studies/case series
- Limited short term followup
- No consensus guidelines on PJK prevention

Future Directions

- Validate and define thresholds “patient specific” for SVA, TK, LL, PI, PI-LL, T1PA
- Bone mineral density: Osteopenia/Osteoporosis with DEXA vs Hounsfield CT
- Validation of the GAP score
- Clinically significant PJK/PJF
Personal Approach

• **Preop**
  1. DEXA scan (goal T > -2.5) (Metabolic bone clinic, Ca, Vit D)
  2. Appropriate UIV selection

• **Intraop:**
  1. Meticulous dissection at the UIV
  2. Maintain Interspinous ligament & fascia, facet capsule at UIV
  3. Exposure limited to screw entry point
  4. Screws at UIV (more anatomic screw placement)

• **Post-op:** Jewett Brace when OOB, Continue Ca, Vit D
THANK YOU
Surgical Site Infection
Contemporary Postoperative Management

Alexander R. Vaccaro, MD, PhD, MBA
Professor, Chairman
Department of Orthopaedics and Neurosurgery
Thomas Jefferson University
President Rothman Institute
Philadelphia, PA

Disclosures

• Grant Support/ Royalties/Stock options/Private Contractor:
• President: Rothman Institute
CDC Definition

- **Superficial Incisional SSI (within 30d)**
  - Involves Skin and SubQ tissue

- **Deep Incisional SSI (within 90d)**
  - Abscess or other evidence of infection in deep tissue (fascia) detected on gross/histo exam

- **Organ/Space SSI (within 90d)**
  - Purulent drainage from a drain that is placed into the organ/space (e.g. closed suction drainage system, open drainage, T-tube drain, CT-guided drainage) or abscess/other evidence of infection involving organ/space


Timing

- **No strict definition (varying definitions in literature)**
  - Early infections typically < 30 days
    - Presenting symptoms: fever, weight loss, erythema, swelling, warmth, tenderness, and elevated WBC
    - Wound drainage is reliable and specific. Radcliff KE, Spine J, 2015
  - Late infections typically > 90 days
    - Typically present with delayed symptoms: chronic pain, lack of adequate fusion or implant failure months after surgery.
    - Wound drainage is less common than early infections. Kasliwal, Surg Neurol Int, 2013

- Differentiation between early and late can be important for treatment (implant retention vs. removal).
Why Be Concerned

- Patients Perceive Infections To Have Significant Long Term Effects
  Hart, Spine, 2013

- Decreased Perception of Surgery Success (controlling for LBP)
  Petilon JM, Spine, 2012
  Bono, Spine, 2013
  Falavigna, JNS Spine, 2011

Effect of SSI on outcome

- Propensity-matched study, 30 infected lumbar fusions, 2 yr f/u
- Infected group-significantly more pain, poorer quality of life and worse Oswestry function outcomes

Petilon, Spine, 2012
Delayed Recovery

- Secondary analysis 535 pts (79 SSIs) who underwent thoracolumbar surgery from a previous RCT (investigating antibiotic dosing)
- Among infected pts- Higher rate of: CSF leak (6.3% vs. 0.4%, p=0.014), hematoma (6.3% vs. 1.3%, p=0.001), post-discharge ED visit (11.4% vs. 2.6%, p=0.001), and hospital readmission (46.8% vs. 3.3%, p=0.001)
- Pt reported outcomes: worse MCS-12 at baseline; 1.5, 3 and 6 months postoperatively; worse PCS-12 at 6 months postoperatively
- SSI-negative impact short term, differences resolved after 6 months

Incidence Variable!

<table>
<thead>
<tr>
<th>Population</th>
<th>Rate</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medicare Cervical</td>
<td>4.4%</td>
<td>Wang TSJ 2012</td>
</tr>
<tr>
<td>Medicare Lumbar</td>
<td>15-19%</td>
<td>Wang TSJ 2012</td>
</tr>
<tr>
<td>Medicare Fusion</td>
<td>8.5% primary and 12.2% revision</td>
<td>Kurtz JNS Spine 2012</td>
</tr>
<tr>
<td>SPORT IDH</td>
<td>2%</td>
<td>Weinstein JAMA 2006</td>
</tr>
<tr>
<td>SPORT Stenosis</td>
<td>2.5%</td>
<td>Weinstein Spine 2010</td>
</tr>
<tr>
<td>SPORT Degen Spondy</td>
<td>4%</td>
<td>Weinstein Spine 2010</td>
</tr>
<tr>
<td>AO Spine CSM</td>
<td>2% superficial, 0.7% deep</td>
<td>Wilson JR Spine 2012</td>
</tr>
<tr>
<td>Prospective TJUH</td>
<td>16%</td>
<td>Campbell JNS 2012</td>
</tr>
<tr>
<td>Prospective Trauma</td>
<td>3.5%</td>
<td>Lonjon Orthop Trauma Surg Res 2012</td>
</tr>
<tr>
<td>STASCIS</td>
<td>3.4%</td>
<td>Wilson, JR, JNS, 2012</td>
</tr>
</tbody>
</table>
Known Risk Factors

- **Procedure**
  - Duration
  - EBL
  - Bone Graft-Allograft
  - Transfusion
  - Instrumentation
  - Approach
  - Interbody Fusion
  - Oxygenation
  - Indications
  - PEEK Implant
  - Loupes
  - Microscope

- **Patient Comorbidities**
  - Steroid Therapy
  - Diabetes
  - Smoking
  - Age
  - BMI
  - Glucose Level
  - Nutrition
  - ASA Score
  - Prior Spine Surgery
  - Hypoalbuminemia
  - SCI
  - Discharge Facility

What to do with DMARDS?

- **Nonbiologic DMARDs:**
  - Methotrexate
  - Leflunomide
  - Hydroxychloroquine
  - Sulfasalazine
  - Recommendation is to continue these. *Galetta, CSS, 2019*

- **Biologic DMARDs:** (etanercept, adalimumab, abatacept).
  - Recommend withholding and plan surgery at the end of the dosing cycle.

- Other SLE specific medications (mycophenolate mofetil, azathioprine, cyclosporine, tacrolimus)
  - Decision to withhold should be made on an individual basis
Hyperglycemic Effect

- Risk Factor: surgical stress, activation of hypothalamic-pituitary axis
- Uncontrolled: impairs immune system
- Odds Ratio 2.9 [1.2, 6.5] for postoperative SSI if postoperative hyperglycemia (> 200 mg/dL)
Subcutaneous Fat

- Subcutaneous fat thickness, not BMI, risk for SSI

Epidural Injections

- Preoperative ESI associated with increased risk of postoperative lumbar infection
  - 1 month ➔ OR 3.2
  - 1-3 months ➔ OR 1.8

- Preoperative ESI associated with increased risk of postoperative cervical infection
  - 3 months ➔ OR 2.21
  - 3-6 months ➔ OR 1.95
  Cancienne, Spine, 2016
Other Infection Risk Factors

- Case Order
- Decompression - 3x Increased Rate if 3rd Case vs 1st Case
- Increased in Summer/Fall

Gruskay, Vaccaro, Spine, 2012
Gruskay, Vaccaro, JNS, 2013

Frailty Index Predictive of Complications

N=18,294
Surgical Invasiveness Index

- n = 1532; Therapeutic Level III evidence
- Inclusion: > 18yo, no prior SSI, invasiveness index > 0

<table>
<thead>
<tr>
<th>Surgical Invasiveness Index</th>
<th># Cases</th>
<th>OR Infection</th>
<th>CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical Invasiveness Index: 1 - 5</td>
<td>14</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Surgical Invasiveness Index: 6 - 10</td>
<td>19</td>
<td>2.42</td>
<td>1.22 - 4.77</td>
<td>0.009</td>
</tr>
<tr>
<td>Surgical Invasiveness Index: 11 - 15</td>
<td>14</td>
<td>3.07</td>
<td>1.48 - 6.33</td>
<td>0.002</td>
</tr>
<tr>
<td>Surgical Invasiveness Index: 16 - 20</td>
<td>6</td>
<td>3.36</td>
<td>1.32 - 8.52</td>
<td>0.008</td>
</tr>
<tr>
<td>Surgical Invasiveness Index: 21 - 25</td>
<td>3</td>
<td>3.36</td>
<td>1.00 - 11.3</td>
<td>0.04</td>
</tr>
<tr>
<td>Surgical Invasiveness Index: 25 - 48</td>
<td>7</td>
<td>5.34</td>
<td>2.23 - 12.8</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Cizik, JBJS, 2012

Delay in Diagnosis

- Average delay in diagnosis 1-3 months from onset symptoms
- Delay > 8 wks-predictor of lower recovery rates, increased neurologic deficits and long-term disability
Organisms

- **MRSA** - 35% S. aureus infections in primary cases, 48% revision surgery

- **Staphylococcus epidermidis** (coagulase-negative staph) - associated spinal instrumentation (31.4% percent of SSIs)

- **Gram-negative bacteria** (Enterococcus, E. coli, and Peptostreptococcus) - 30%, more common lumbosacral junction due to proximity to the perianal area

- **Cutibacterium acne** (Propionibacterium acnes), anaerobic organism - common delayed surgical site infection with spinal instrumentation

When do labs normalize in non-infected patients?

- **WBC/ESR/CRP**

- Normal by POD 7

Choi, J Kor Neurosurg, 2014
Novel Laboratory Tests

• **Serum Amyloid A (SAA)**
  - Short half-life (reaches peak on POD 3 and decreases rapidly)
  - Not affected by steroids

• **Procalcitonin**
  - Serum peptide that is elevated in inflammation and infection.
  - Specificity for bacterial infections in sepsis.
  - Inconclusive Evidence

---

Presepsin Level (PSEP) for early diagnosis of SSI

• Infection-free spinal surgery, reference values:
  - <620 pg/mL immediately after surgery, and
  - <300 pg/mL 1 week after surgery
MRI Diagnosis

- Case control study reviewing postop MRIs
- 17 Infections
- 64 Control (non-infections)
- Pedicle Screw Sign: 5mm high signal around screw heads but not T1
- 88% Sensitive, 89% specific, 96% NPV

Kimura, JSDT, 2013

Pedicle Screw Sign

- Positive
- Negative

Kimura, JSDT, 2013
Comparison of PET vs MRI in postoperative patients

- N=30, postoperative spine fusions who had deep SSI
- PET/CT and MRI performed 1 month after cessation of antibiotics
- PET superior. No metal artifact from PET

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRI</td>
<td>66.6</td>
<td>61.9</td>
<td>33.3</td>
<td>86.6</td>
</tr>
<tr>
<td>PET/CT</td>
<td>85.7</td>
<td>82.6</td>
<td>60.0</td>
<td>95.0</td>
</tr>
</tbody>
</table>

Dauchy, Clin Micro Infect, 2016

PET Diagnosis of Postoperative Infection

- 26 y/o with AIS status post T5 to L4 fusion
- 4 Months postop, Persistent pain
- Xrays negative
- PET positive

Dauchy, Clin Micro Infect, 2016
Systematic Review–Prophylactic postoperative measures to minimize surgical site infection

Postoperative Measures

- **Optimal type of postoperative dressing**
  - Insufficient evidence

- **Dressings duration**
  - Insufficient evidence

- **Shower Postoperative**
  - Insufficient evidence

- **Wound drain**
  - High quality evidence – wound drain does not change/alter rate of SSI

Tan, TSJ, 2019
Screening and Eradication

- Carriers MSSA 2-3X, MRSA 8-10 X Risk SSI
- + Pts- 2% mupirocin ointment applied intranasally with 2% chlorhexidine gluconate (CHG) showers for five days before the surgical procedure.
- +MRSA- vancomycin 15mg/kg prior to skin incision for 24 hours after surgery

Preoperative MRSA Nasal Colonization

- Meta-analysis, 7 studies- SSI rates in MRSA nasal-colonized patients vs those without colonization
- MRSA-colonized pts-higher rate SSI
- Pts without decolonization- higher rate of SSI than those who were decolonized
- Conclusion: colonized patients are at increased risk, and decolonizing may help prevent development of SSI
Intraoperative: Skin Antisepsis

- Meta-analysis- alcohol-based agents are likely superior to aqueous solutions and that chlorhexidine may decrease SSI rates compared to povidone-iodine (DuraPrep)

Siddhwa, Surgical Infections, 2015

Prevention

- Local Vancomycin Powder
  - All studies demonstrate significant decrease in SSI
  - Complications
    - Wound Drainage, Sterile Seroma, Anaphylactic Rxn, Vancomycin Flushing Syndrome, Nerve Irritation

Godil, J Neurosurg Spine, 2013
Youssef, Evid Based Spine Care J, 2014
Mariappan, J Neurosurg Spine, 2013
Intrawound Vancomycin Powder
Posterior Spinal Surgery

- 1261 patients
- Propensity score-matched into 444 pairs to limit differences in baseline and surgical data
  - No differences between pairs except for height
- Vancomycin group had reduced risk of SSI (2.7% vs. 5.4%, OR 0.486 CI 0.243-0.972, p=0.041)
- Conclusion: intrawound vancomycin powder is useful in reducing risk of SSI after posterior spinal surgery

Ushirozako, J Neurosurg Spine, 2021

Sodium oxychlorosene-based solution for wound irrigation

- Protocol: irrigate with 1L sodium oxychlorosene (0.05%) via pulse lavage
- Rinse with normal saline, add 1-2g intrawound vancomycin powder, and 1-2 surgical drains
- 5047 patients - protocol reduced infection rate from 3.5% to 1.2% (p<0.001)

Alentado, J Neurosurg Spine, 2021
Antibacterial Resistance

- 10-yr follow-up (n = 113)
- No association between vancomycin-resistant bacteria found in SSI and vancomycin application.
- An increase in gram (-) infections in patients that received topical vancomycin

Khanna, Spine Deformity, 2019

NASS Guidelines

- NASS guidelines regarding antibiotic prophylaxis in spine surgery
  - Consensus statement suggesting the use of vancomycin powder in instrumented, or complicated spine surgery, or for patients with comorbidities such as diabetes, neuromuscular disease, cord injury, or trauma.

Shaffer, NASS, 2013
What to do about Gram Negative Infections

• Tobramycin powder 1.2g in addition to vancomycin powder
• In vitro data:
  • Good activity against 98% bacterial tested
  • Scott, JBJS Br, 1999
  • Improved activity against pseudomonas vs gentamicin
    Scott, JBMR, 2003

Tissue Sampling

Intraoperative Tissue Samples
• No strict criteria in spine literature on how many samples to take
• PJI literature-3-5 culture samples
  • Send for anaerobic, aerobic, fungal and TB.
  • Hold for 21 days for P. acnes.
**Intervertebral Cage**

- Most can be successfully retained with initial salvage attempt at I&D with antibiotics.

**Algorithm?**

- How do you decide:
  - Primary closure
  - Vac
  - Flaps
  - Remove Hardware
Treatment

• Key Issue is Timing
  • Early Infection (<30 Days)
    • I&D & Hardware Retention
  • Delayed Infection
    • I&D & Hardware Removal

• Antibiotic Suppressive Therapy
  • Instrumentation Retained – IV followed by Long-Term Oral
  • Instrumentation Removed – Shorter Treatment Course

Lall, J Clin Neurosci, 2015

Treatment

• Postoperative Infection
  Treatment Score for the Spine (PITSS)
  • Predictor of Repeat I&D & Failed Single-Stage 1° Closure
  • Score 7-14 = Low Risk
  • Score 15-20 = Indeterminate Risk
  • Score 21-33 = High Risk
    • Need for 2-Stage Reconstruction

PITSS to predict likelihood of requiring two-stage reconstruction after postoperative infection

<table>
<thead>
<tr>
<th>Predictors</th>
<th>PITSS score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spine location</td>
<td></td>
</tr>
<tr>
<td>Cervical</td>
<td>1</td>
</tr>
<tr>
<td>Thoracolumbar</td>
<td>2</td>
</tr>
<tr>
<td>Lumbar/sacral</td>
<td>4</td>
</tr>
<tr>
<td>Comorbidities</td>
<td></td>
</tr>
<tr>
<td>None/other</td>
<td>0</td>
</tr>
<tr>
<td>Cardiovascular/pulmonary</td>
<td>1</td>
</tr>
<tr>
<td>Diabetes</td>
<td>4</td>
</tr>
<tr>
<td>Microbiology</td>
<td></td>
</tr>
<tr>
<td>Gram positive</td>
<td>2</td>
</tr>
<tr>
<td>Gram negative or polymicrobial without MRSA</td>
<td>4</td>
</tr>
<tr>
<td>Polymicrobial with MRSA or MRSA alone</td>
<td>6</td>
</tr>
<tr>
<td>Distant site infection</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1</td>
</tr>
<tr>
<td>UTI/PNA</td>
<td>3</td>
</tr>
<tr>
<td>Bacteremia alone</td>
<td>5</td>
</tr>
<tr>
<td>Bacteremia + PNA/CTI</td>
<td>6</td>
</tr>
<tr>
<td>Instrumentation</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>6</td>
</tr>
<tr>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>Bone graft</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1</td>
</tr>
<tr>
<td>Autograft</td>
<td>3</td>
</tr>
<tr>
<td>Other (allograft, BMP, and synthetic)</td>
<td>6</td>
</tr>
</tbody>
</table>

Antibiotic Treatment

- Typical treatment range: 6 weeks IV abx + 4-6 weeks of oral antibiotics
- Generally targeted against a single isolated organism.
  - *Staph spp. most common*
  - MRSA
  - *P. acnes*
- Rifampin can be added to penetrate biofilms
- Fluoroquinolone resistance
  - 30% of spine SSI are associated with GN.
  - If resistant to fluoroquinolones, can treat with β-lactams or oral Bactrim.

Controversies

1. Benign appearing wound
2. Use of BMP
BMP’s and Spinal Infections

Table 28.1 Summary of Level IV Evidence Data Regarding Use of BMP in Spinal Infection

<table>
<thead>
<tr>
<th>Study</th>
<th>Mean Follow-Up</th>
<th>Treatment Group</th>
<th>Complications</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen et al (2007)†</td>
<td>22 months (11-30 months)</td>
<td>14 patients Cervical (2 pts) Thoracic (1 pt) Thoracolumbar (3 pts) Lumbosacral (7 pts)</td>
<td>Four complications in two patients: one durotomy, one patient had three complications: ureteral tear during approach (repaired), postop cage dislodgment day 1, small bowel obstruction during stay requiring partial bowel resection</td>
<td>All patients fused at latest follow-up Seven of the eight patients with neurological deficits recovered completely (quadriplegia unchanged) Mean visual analogue scale pain scores improved from 7.9 to 2.8 at 1 year (p &lt; 0.05), No recurrent infections No patient outcome measures All patients fused (100%) at latest follow-up No recurrent infections</td>
</tr>
<tr>
<td>Aryan et al (2007)‡</td>
<td>20 months (no range given)</td>
<td>15 patients Cervical (6 pts) Thoracic (5 pts) Lumbar (4 pts)</td>
<td>Wound; two superficial infections, packed, healed secondary intention Dysesthesia or dysphagia in four pts, resolved in three by postop day 4; one patient required feeding tube 6 wks. One intraoperative large vein injury, repaired. Surgical: one durotomy—successful treatment with subarachnoid drain Two major vessel injuries during approach (repaired) by vascular approach surgeons</td>
<td>Odom criteria at final follow-up: excellent (3; 15%), good (12; 60%), fair (4; 20%), and poor (1; 5%). Frankel grades: 14 patients stable, and six patients improved grades after surgery No case of persistent or recurrent infection</td>
</tr>
<tr>
<td>O’Saughnessy et al (2008)§</td>
<td>40 months (24-53 months)</td>
<td>20 patients Thoracic (1 pt) Thoracolumbar (5 pts) Lumbosacral (11 pts) Lumbosacral (3 pts)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions

- SSI-Potential High Morbidity & Associated Cost
- Body of Literature Expanding Rapidly
  - Very Little Level I Evidence
- Thorough Knowledge of Risk Factors
  - Stratify Patients Preoperatively
- Multifaceted Approach to Prevention & Management
DISTINGUISHING STRUCTURAL SAGITTAL IMBALANCE FROM PSEUDO-SAGITTAL IMBALANCE RELATED TO SPINAL STENOSIS

Sina Pourtaheri, MD
Gulf Coast Orthopedics

Disclosures

• No Relevant Disclosures relevant to this talk
CURRENT THOUGHT PROCESS ON SAGITTAL IMBALANCE

1. It's Structural
2. Match Lumbar Lordosis to Pelvic Incidence
3. Fuse the Segments to Meet these Goals

FLAWS IN CURRENT THOUGHT PROCESS

1. Most of the Time it's NOT Structural
2. Asymptomatic Patients have PI-LL Mismatch
3. Treat the CAUSE of the Deformity
• 49 Asymptomatic Patients
• 66 Adult Scoliosis

Correlation Coefficient for PI to LL:
• 0.60 for Normal Subjects
• 0.45 for Scoliotic Patients

So PI DOES NOT match LL in asymptomatic subjects
TRANSLATE THOUGHTS ON PELVIC INCIDENCE TO HRQOL FOR POSTOP PATIENTS

• Schwab, NYU

Pelvic Tilt and Truncal Inclination
Two Key Radiographic Parameters in the Setting of Adults With Spinal Deformity

• Retrospective Review

Table 2. Data From a 125 Patient Retrospective Review of Clinical Outcomes Correlated With Clinically Relevant Radiographic Values for 3 Key Parameters

Oswestry Disability Index (ODI)

<table>
<thead>
<tr>
<th>Group</th>
<th>SVA</th>
<th>PT</th>
<th>PI-LL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt;50</td>
<td>&gt;20</td>
<td>&gt;9</td>
</tr>
<tr>
<td>2</td>
<td>&lt;50</td>
<td>&gt;20</td>
<td>&gt;9</td>
</tr>
<tr>
<td>3</td>
<td>&lt;50</td>
<td>&lt;20</td>
<td>&gt;9</td>
</tr>
<tr>
<td>4</td>
<td>&lt;50</td>
<td>&lt;20</td>
<td>&lt;9</td>
</tr>
<tr>
<td>5</td>
<td>&lt;50</td>
<td>&lt;20</td>
<td>&lt;9</td>
</tr>
</tbody>
</table>

Mean radiographic parameter value
Mean ODI scores
Unpaired t tests on ODI scores
• PI constant in childhood, then increases in adolescence, then stabilizes in adulthood

PELVIC INCIDENCE IS NOT CONSTANT, IT CHANGES
ONE OF MY RESEARCH INTERESTS IN ADULT DEFORMITY

• Flexible Sagittal Imbalance is often POSTURAL and the POSTURE is COMPENSATORY for LUMBAR STENOSIS

The Utility of Preoperative Magnetic Resonance Imaging in Predicting the Flexibility of Flatback Deformities

Authors: Sina Pourtaheri*, MDi, Jason Savage, MDii, iv, Iain Kalfas, MDii, v, Thomas E. Mrozii, iv, Edward Benzelii, v, Michael Steinmetzii, v

ii Center for Spine Health, Neurological Institute, Cleveland Clinic, Cleveland, OH, USA
iv Department of Orthopedic Surgery, Cleveland Clinic, Cleveland, OH, USA
v Department of Neurosurgery, Cleveland Clinic, Cleveland, OH, USA

Pelvic Retroversion is Compensatory for Lumbar Stenosis

Authors: Sina Pourtaheri*, MDi, Jason Savage, MDii, iv, Iain Kalfas, MDii, v, Thomas E. Mrozii, iv, Edward Benzelii, v, Michael Steinmetzii, v

ii Center for Spine Health, Neurological Institute, Cleveland Clinic, Cleveland, OH, USA
iv Department of Orthopedic Surgery, Cleveland Clinic, Cleveland, OH, USA
v Department of Neurosurgery, Cleveland Clinic, Cleveland, OH, USA
Compensatory Lumbar Flexion due to Spinal Stenosis

No Stenosis

Lumbar Stenosis

Compensatory Lumbar Flexion both Proximally and Distally in Cases of Lumbar Stenosis

Normal Lumbar Lordosis (L1-L5)

Proximal Lumbar Flexion (L1-L3)

Distal Lumbar Flexion/Pelvic Retroversion (L4-S1)
COMPENSATED & DECOMPENSATED SAGITTAL IMBALANCE

MRI COMPARED TO STANDING X-RAYS PREDICTS FLEXIBILITY OF A DEFORMITY

MRI | Standing | Intraoperative

15

16
Flexible Sagittal Imbalance and Pelvic Retroversion as a Result of Proximal and Distal Lumbar Flexion

Concomitant Lumbar Stenosis at L3-L5 in a Patient with Flexible Sagittal Imbalance
THE CLINICAL CONUNDRUM!

<table>
<thead>
<tr>
<th>SAGITTAL IMBALANCE</th>
<th>LUMBAR STENOSIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>AXIAL BACK PAIN (PARASPINAL MUSCLE EXT)</td>
<td>AXIAL BACK PAIN (SINUVERTEBRAL NERVE)</td>
</tr>
<tr>
<td>STANDING INTOLERANCE</td>
<td>STANDING INTOLERANCE (SHOPPING CART)</td>
</tr>
<tr>
<td>RADICULOPATHY (QUAD SPASMS/ FATIGUE)</td>
<td>RADICULOPATHY</td>
</tr>
<tr>
<td>PELVIC RETROVERSION</td>
<td>PELVIC RETROVERSION</td>
</tr>
</tbody>
</table>

SUMMARY

• Pelvic Incidence is NOT CONSTANT
• Asymptomatic Patients HAVE PI/LL MISMATCH
• Sagittal Imbalance is NOT PURELY STRUCTURAL in many case
• Flatback (Lose of LL) and subsequent sagittal imbalance is COMPENSATORY for LUMBAR STENOSIS in many cases
SUMMARY

• Pelvic Tilt/Pelvic Retroversion is COMPENSATORY for LUMBAR STENOSIS in select patients
• Patients with Sagittal Imbalance is a CLINICAL CONUNDRUM
• Treat the CAUSE of the Malalignment, not the Malalignment alone

‘THE CONE OF ECOMONY’ – JEAN DUBOUSSET
The treatment of spondylolisthesis: adult and pediatric

Serena S. Hu, MD
Professor and Vice Chair
Chief, Spine Service
Department of Orthopedic Surgery
Professor, by courtesy
Department of Neurological Surgery
Stanford University

Disclosures

- Board membership:
  - American Orthopedic Association
  - Scoliosis Research Society
- Journal editorial roles:
  - Global Spine Journal (deputy editor)
  - Spine Deformity (editorial board)
- Intellectual property: OnPoint, MiRus

Manchikanti et al (2016) BMJ Open
Lee et al (2012) Spine
Cohen et al (2014) Anesthesiology
Strub et al. (2007) J Vasc Interv Radiol
Classification of spondylolisthesis

- Wiltse most commonly used
  + Post surgical
- Most common types:
  - Degenerative
  - Isthmic
    - Low grade
    - High grade

Conservative treatment

- Outcomes (SPORT study, Pearson et al, 2008)
  - Improved if “hypermobile” (10% or 10°)
  - Worse for grade II spondylo (compared to Gr I, v surgical outcomes)
Degenerative spondylo: Surgical v conservative outcomes

- 303 randomized, 304 observational
- Failed 12 wks conservative Rx

Surgical indications

- Progressive neurologic deficit
- Intractable pain
- Progression of deformity
Surgical considerations

- Decompression only
- Decompression and fusion
- Reduction
- Interbody fusion
  - TLIF, PLIF,
  - XLIF, ALIF

Meta-analysis (Mardketko, 1994)
- 152 papers → 25 papers, 889 pts
  - Decomp only 69% satisfaction
  - Decomp/fusion 86-90%

Neurosurgical literature (Epstein, 1998)
- 290 pts, 10 y avg f/u
  - Prolo scale: 69% E, 13% G results
  - 2.7% required fusions later
Interbody fusion: possible indications

- Pars defect
  - Plump disc space
- Significant slippage
- Reduction indicated
- High lordosis angle (↑ shear forces)

Outcomes after decompression /fusion for DS: effect of type of fusion

- 380 surgical patients:
  - 80 fusion in situ (21%) PLF
  - 213 instrumented fusion (56%) PPS
  - 63 circumferential fusion (17%) 360°
  - 23 decompression only (6%)
- Fusion rate
  - 67% PLF
  - 85% PPS
  - 87% 360°
Isthmic spondylo: Low grade

- L5-S1 most common
- Younger patients
- May have history of hyperextension sports
Pars repair

- Ideal for higher pars fx
- Need healthy disc, min slippage

Complications

- Incomplete pain relief
- Neurologic injury
- Pseudoarthrosis
- Adjacent segment degeneration
High grade spondylolisthesis

- High grade: greater than 50% slippage

- High slip angle

- Lumbosacral kyphosis

Clinical differences

- Stance:
  - vertical (flexed) pelvis “retroverted”
  - hips unable to hyperextend
  - heart-shaped pelvis

- Gait:
  - Phalen-Dickson sign-hips flexed, knees flexed
Neurologic findings

- Radicular symptoms
  - Foot drop
  - Bowel/bladder
- Hamstring tightness
  - Caused by stenosis or pelvic retroversion?

Indications for spondylo reduction

- inability to stand upright
- sagittal imbalance
- need for decompression
- progression
- poor clinical appearance
- slip angle >40 deg
High-grade spondylo

Techniques of reduction

- traction
- cast reduction
- instrumented reduction
- Resection L5 (Gaines procedure)
Instrumented reduction

- Distal fixation
  - transacral screws
  - S2 screws
  - iliac fixation
    (iliosacral, iliac)
  - Jackson intrasacral screws

- Must perform laminectomy
- Slow process
  - Check nerve roots
  - Distraction (L3 screw or hook), then translation
  - L5-S1 discectomy
  - +/- or sacral dome osteotomy
Instrumented reduction

- interbody fusion:
  - transacral fibula
  - mesh cage
Instrumented reduction

- wide decompression
- distraction applied
  - viscoelasticity
- instrumentation to L4
- sacralplasty if needed
- translation applied
- relaxation of distraction

Instrumented posterior fusion

- Edwards (Curcin and Edwards, SRS 1994)
- reduce anatomically
- neuro risk greater for spondyloptosis
- 20 patients with GrV
  - neuro risk 65%, 25% permanent
  - 20% pseudo rate
- Hardware failure risk (S2 screw)
Reduction for failed fusion in situ

Hu, Bradford et al, 1996
- reduce slip angle to <45 degrees
- 25% neuro risk, only 1/16 had perm deficit
- slip 89% --> 24%; SA 50 deg--> 24 deg
- 4 hardware failures: revised
- 15 pts G/E results
- interbody fusion if SA not <45 deg

Instrumented posterior fusion
Caveats for reduction

- slow reduction
- frequent wake up tests
- Neuromonitoring: EMG, motors, sphincter
- check nerve roots constantly
- complete reduction: higher neuro injury

Complications

- hardware pullout
- neuro injury: L5, cauda equina
- pseudoarthrosis
Effect of reduction on L5 root

- Petraco et al, 1996
- nerve strain 4% for 1st 50%
- nerve strain 10% for 2nd 50%
- L5 rotated at 100% slip --> nerve excursion decr 5.2 mm
- L5 rotated at 0% slip--> nerve excursion incr 3.1 mm
- Partial reduction advocated

Partial reduction, transsacral fibula/screws

- Smith, Deviren, Berven, Bradford, Spine 2001
- 9 patients, G3 or 4 spondylo
- Partial reduction, transacral fibula
- 2 w/o instrumentation: fractured fibula, revised
- 2 transient EHL weakness
- improved outcomes, less good for revisions
Outcomes

• Overall
  • Decomp: 69-71% satisfaction
  • Decomp/fusion: 85-95%
• Fusion rate improved with instrumentation
  • No short term effect on outcomes
  • Probably long term effect

Conclusion

• Similar principles for treating different types of spondylo
• Surgical success good
• Complications usually manageable
• Reduction of high grade spondylo has higher complication rate: proceed with care
My Perspective on MIS Deformity Surgery

Praveen V. Mummaneni, MD, MBA
Joan O'Reilly Endowed Professor in Spinal Surgery
Vice-Chairman, UCSF Dept. of Neurosurgery
Co-director: UCSF Spine Center
Director: MIS/Complex Spine Fellowship
University of California, San Francisco

Nitin Agarwal, MD
Complex Spine Fellow
UCSF Dept. of Neurosurgery

Saman Shabani, MD
Complex Spine Fellow
UCSF Dept. of Neurosurgery

Jeremy Huang, BS
Clinical Research Coordinator
UCSF Dept. of Neurosurgery

Disclosures/Funding Sources

- Consultant: DePuy Spine, Globus, Nuvasive, Stryker
- Other Financial Support (royalty): Thieme Publishing, Springer Publishing
- Stock: Spinicity/ISD
- Grants/Funding Sources:
  AO Spine (Spine Fellowship Grant)
  ISSG (MIS Deformity)
  NREF (QOD)
  PCORI (CSM-S Trial)
  Alan and Jacqueline Stuart Spine Outcomes Center (SLIP-II)
  Joan O'Reilly Endowed Professorship
  NIH/NIAMS U19AR076737 (UCSF REACH)
Why Would We Want To Do “Less” Surgery for Adults?

- Aging Population
- Complication rates high
  - Comorbidities
- Pseudoarthrosis rates problematic
  - Osteoporotic

When To Do MIS for Deformity?

- Need an algorithm...

NS FOCUS May 2014:
- Praveen Mummaneni
- Chris Shaffrey
- Lawrence Lenke
- Paul Park
- Michael Wang
- Frank LaMarca
- Justin Smith
- Greg Mundis
- David Okonkwo
- Bertrand Moal
- Richard Fessler
- Neel Anand
- Juan Uribe
- Adam Kanter
- Behrooz Akbarinia
- Kai Ming Fu
- MIS ISSG
MIS techniques are advancing

The Algorithm is evolving...

CLASS I
MIS surgery with decompression only or fusion of a pathologic level.

CLASS II
Multi-level MIS surgery with/without decompression and interbody fusion.

CLASS III*
Circumferential MIS with ACR, mini-open PSO, expandable cage technology, and/or hybrid-open approaches.

CLASS IV
Open surgery with osteotomies +/- extension of fusion to the thoracic spine.

Fused or Rigid Spine

>5 level fusion including L5-S1 or >10 segments needing treatment or pre-existing multi-level instrumentation.

LL-PI mismatch < 10°, thoracic kyphosis < 60°, and thoracolumbar kyphosis < 10°

SVA < 6 cm

PT < 25

LL-PI mismatch < 10°

Coronal Cobb < 20°
Minimally Invasive Interbody Selection Algorithm (MIISA) for spinal deformity

<table>
<thead>
<tr>
<th>L1-4</th>
<th>L4-5</th>
<th>L5-S1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximize Height Restoration/Lordosis</td>
<td>Maximize Height Restoration/Lordosis</td>
<td>Maximize Height Restoration/Lordosis</td>
</tr>
</tbody>
</table>

LLIF: Proposed of transverse lateral interbody fusion; use when up to 5° of segmental lordosis is desired. Lordosis between L1-4 is inconsistent while height restoration is consistent.

ACR: Use when ≥ 10° of segmental lordosis is desired.

TLIF: Allows direct decompression of foraminal/lateral recess stenosis.
Case 1

MISDEF CLASS 2
Awake Spinal Surgery
SVA= -1cm
PI= 69°
LL= 57°
PI-LL= 12°
SS= 40°
PT= 29°
T-cobb= 27°
L-cobb= 36°

55 yo physician
- Has mild back pain and severe sciatica due to L4-5 up/down stenosis and spondylolisthesis
- Failed a laminoforamenotomy
SV A= 0 cm
PI= 69°
LL= 62°
PI-LL= 7°
SS= 43°
PT= 26°
T-cobb= 27°
L-cobb= 36°

• D/c’d home on POD #1

• Returned to work as a physician 3 weeks post-op

• MIS TLIF gives direct foraminal decompression, and mild increase in lordosis
Case 2

MISDEF Class 2
Obese Patient

• 68 F
• Morbid obesity – 300 lbs
• Multiple prior cervical operations
• L4/5 laminectomy in the past
• Currently - back and right leg pain
• Failed conservative management
  PT, ESI
  On methadone and oxycodone
L2-3 stenosis and listhesis
L3-4 stenosis

L4-5 Stenosis and Listhesis and left facet cyst
DISH Autofusion of L1-2 and L5-S1

MIS Interbody Fusion Algorithm for Lumbar Deformity (no prior retroperitoneal surgery)

Maximize Height Restoration/Lordosis

L1-L4

LLIF

L4-5

Maximize Height Restoration/Lordosis

TUF

ACR

L5-S1

Maximize Height Restoration/Lordosis

ALIF

LLIF: Preperitoneal or transperitoneal interbody fusion; use when up to 5° of segmental lordosis is desired.

Lordosis between L1-L4 is inconsistent while height restoration is consistent

ACR: Use when ≥10° of segmental lordosis is desired

TUF: Allows direct decompression of foraminal/lateral recess stenosis
Stage 1:
L2/3, L3/4, L4/5
MIS LIF
Navigation

L2-5 Transpsoas Lateral Fusion
L2-S1 MIS PSF

Stage 1;
L2/3, 3/4, 4/5 MIS transpsoas LIF

Stage 2;
L2-S1 perc screws
CT navigation
Left L4/5 MIS lami/forami
- **Stage 2**
  - L2-S1 percutaneous pedicle screws
  - Left iliac bolt
  - Left L3/4, L4/5, L5/S1 MIS laminoforaminotomies
  - Intraop CT navigation
Case Example, Class 2

- 80 year old male
- severe back and left leg pain in the setting of asymmetric disc collapse

Pre-op SVA: 10.6cm
Pre-op PI-LL: 17°

Case Example, Class 2

-L2-5 LLIF and MIS posterior instrumented fusion
- achieved good relief of symptoms.

Post op SVA: 5.8cm
Post op PI – LL: 1°
Case 3, Class 2:

- 62-year-old female who underwent prior L4-5 fusion
- She developed worsening back and radicular pain
- Imaging revealed severe L1-3 scoliosis and L3-4 lateral listhesis

Clinical Presentation

- Pre-op x-rays
  SS = 37 degrees
  PI = 55 degrees
  PT = 18 degrees
  LL = 54 degrees
  SVA = 20.9 mm
  Coronal Cobb>20
• Surgical Plan:
  • Stage 1:
    • L1-L3 LLIF
  • Stage 2:
    • MIS L1-L5 PSF
    • L3-L4 MIS lami
ALIF vs Lateral vs TLIF

Lateral fusion L1-3

Navigation Techniques

• Intraop CT
Watch the distance from iliac reference frame to top screw
Need to consider a spinous process clamp for

Clinical Presentation

- **Post-op**
  
  Resolution of leg tingling and weakness
decrease in pain

  $SS = 32$ degrees
  $PI = 55$ degrees
  $PP = 33$ degrees
  $LL = 46$ degrees
  $SVA = 4.79$ mm
Case 3

MISDEF Class 2
High Sacral Slope

• 58-year-old female
• Low back pain and bilateral leg pain
MIS Interbody Fusion Algorithm for Lumbar Deformity (no prior retroperitoneal surgery)

L1-L4
Maximize Height Restoration/Lordosis
Yes
No

L4-5
Maximize Height Restoration/Lordosis
Yes
No

Maximize Height Restoration/Lordosis
Yes
No

LLIF
ACR
TLIF
ALIF

LLIF: Posterolateral or transpsoas lateral interbody fusion; use when up to 5° of segmental lordosis is desired.
Lordosis between L1-L4 is inconsistent while height restoration is consistent.
ACR: Use when ≥10° of segmental lordosis is desired.
TLIF: Allows direct decompression of foraminal/lateral recess stenosis.
MIS is NOT Ideal for Class 4

- **Avoid**
  - Sag imbalance requiring PSO
  - Thoracic kyphosis
  - Need over 5 levels of interbody fusion
  - Need extension of prior multilevel hardware with 10 levels of fixation
- **These characteristics predict failure with limited MIS decompression/fusion surgery**
- **Need to do OPEN surgery**
MIS is NOT Ideal for Class 4

- Avoid
  - Sag imbalance requiring PSO
  - Thoracic kyphosis
    - Need over 5 levels of interbody fusion
    - Need extension of prior multilevel hardware with 10 levels of fixation
- These characteristics predict failure with limited MIS decompression/fusion surgery
- Need to do OPEN surgery

Radiographic outcomes of anterior column realignment for adult scoliosis deformity: a multicenter analysis.

Deep Minimally Invasive Percutaneous Posterior Redundant Rod Placement: A Prospective Matched Control Analysis.
Treatment of Lumbar Deformities: When is Addressing the Fractional Curve Enough?

Bobby Tay MD
HS Professor of Orthopaedic Surgery
Vice Chair of Quality and Safety
University of California at San Francisco

Disclosures

• Fellowship funding to UCSF from AOA Omega, AO Spine, Nuvasive
• Lumbar fractional curve is the curve below the major lumbar curve in degenerative scoliosis
• L3 or L4-S1
• Disc degeneration, spondylolisthesis, up-down foraminal stenosis on concavity
• L4, L5, S1 root and DRG compression

Incidence and Severity of Back Pain in Adult Idiopathic Scoliosis

ROGER P. JACKSON, MD, FACS
EDWARD H. SIMMONS, MD, BSc, FRCS(C), MS(Tor), FACS
and DANIEL STRIPINIS, BSc, MA, MSc
Fig 2. Correlation of pain with age. The mean age of each pain group increased significantly and almost linearly.

Fig 3. Correlation of pain with curvature. The mean measurements (Cobb method) of the major curves in each pain group increased significantly.

Table 5. Comparison of Pain, Curve Type, and Right versus Left Curves

<table>
<thead>
<tr>
<th>Pain (average)</th>
<th>Number</th>
<th>Type*</th>
<th>Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.10†</td>
<td>22</td>
<td>LS</td>
<td>L</td>
</tr>
<tr>
<td>2.72†</td>
<td>11</td>
<td>TL</td>
<td>R</td>
</tr>
<tr>
<td>2.44†</td>
<td>16</td>
<td>LU</td>
<td>R</td>
</tr>
<tr>
<td>2.38†</td>
<td>47</td>
<td>LU</td>
<td>L</td>
</tr>
<tr>
<td>2.16</td>
<td>25</td>
<td>TL</td>
<td>L</td>
</tr>
<tr>
<td>2.09</td>
<td>45</td>
<td>LS</td>
<td>R</td>
</tr>
<tr>
<td>1.73</td>
<td>80</td>
<td>TH</td>
<td>R</td>
</tr>
<tr>
<td>0.63</td>
<td>56</td>
<td>TH</td>
<td>L</td>
</tr>
</tbody>
</table>

* LS, lumbosacral (fractional); TL, thoracolumbar; LU, lumbar; TH, thoracic.
† These curves were significantly more painful than the other curves ($P < 0.10$).
67% Patients with larger lumbosacral fractional curves had worse correction of coronal deformity after posterior only surgery despite interbody support with TLIF’s
• 78 patients retrospective review
• Fractional curve L3-S1 > 10 degrees
• Radiculopathy on concavity of fractional curve

| Table 5. Complications and outcomes in ALIF versus TLIF groups in 87 adult patients with scoliosis |
|---------------------------------|-------------|-------------|-------------|-----------|
| **Outcome**                     | **Total, N = 87** | **ALIF, n = 44** | **TLIF, n = 23** | **p Value** |
| Any complication; medical or revision surgery | 34 (39.7) | 23 (52.3) | 11 (47.8) | 0.93 |
| Medical complications           | 32 (37.0) | 22 (50.0) | 10 (43.5) | 0.80 |
| Overall revision surgery        | 21 (24.1) | 17 (39.6) | 4 (17.4) | 0.19 |
| Extension surgery due to any cause | 11 (12.4) | 8 (18.2) | 3 (13.0) | 0.734 |
| Extension surgery due to PJK    | 3 (3.5) | 3 (6.8) | 0 (0) | 0.55 |
| Nonextension revision surgery   | 12 (13.9) | 11 (25.0) | 1 (4.3) | 0.046 |
| Discharge to acute rehabilitation | 35 (40.2) | 24 (54.5) | 11 (47.9) | 0.79 |
| 30-day readmission              | 5 (5.7) | 4 (9.1) | 1 (4.3) | 0.65 |
| **Postop spine imaging characteristics** |        |        |            |          |
| Fractional curve                | 6.1° | 5.6° | 7.0° | 0.18 |
| Fractional curve reduction      | 10.8° | 11.7° | 9.0° | 0.967 |
| Pelvic tilt                     | 25.5° | 24.5° | 27.3° | 0.24 |
| Pelvic tilt increase            | -0.71° | -2.1° | 1.9° | 0.127 |
| Lumbar lordosis                 | 42.9° | 42.4° | 42.7° | 0.93 |
| Lumbar lordosis increase        | 5.7° | 9.1° | -0.87° | 0.028 |
| Pelvic incidence – lumbar lordosis mismatch | 15.8° | 14.0° | 19.2° | 0.20 |
| Sagittal vertical axis, cm      | 4.7 | 4.7 | 4.8 | 0.92 |
| Sagittal vertical axis increase, cm | -0.84 | -1.3 | 0.015 | 0.38 |
| Coronal balance magnitude       | 2.2 | 2.6 | 1.5 | 0.029 |
| Coronal balance magnitude increase, cm | -0.50 | -0.38 | -0.72 | 0.61 |
| Scoliosis major curve*          | 12.7° | 18.5° | 20.0° | 0.21 |
| Scoliosis major curve reduction* | 16.0° | 17.9° | 12.4° | 0.17 |

Boldface values indicate statistical significance.

* If a patient had a double major curve, only the curve adjacent to the fractional curve was included in this calculation.
• 100 DLS patients, retrospective case control
• Multicenter spinal deformity database analyzed by age group (25-44, 45-64, 65-85)
• 65-85 group had at baseline greater disability, worse health status, more severe pain than younger cohorts
• 65-85 group had 71% complication rate compared to 42% and 17% rate in the younger cohorts
• Despite higher complication rate, the outcomes were similar (ODI drops to 20-24) and the change is greater. The outcomes sustained at 5 years post-op (Zuckerman GSJ 2021)
- 16 patients, retrospective review, coronal deformity 10-20 degrees
  - Avg age 70 y
  - 8 patients symptomatic from fractional curve
  - 8 patients symptomatic from concavity of major lumbar curve
  - No significant sagittal or coronal imbalance
Multicenter retrospective matched cohort review 106 patients
- 44.3% TLIF, 55.7% ALIF
- No difference in coronal or sagittal correction between ALIF and TLIF
- HQRL less and Rod breakages more in TLIF
Treatment of only the fractional curve for radiculopathy in adult scoliosis: comparison to lower thoracic and upper thoracic fusions

Dominic Amara, BA,1 Praveen V. Mummaneni, MD,1 Christopher P. Ames, MD,1 Bobby Tay, MD,2 Vedat Deviren, MD,3 Shane Burch, MD,4 Sigurd H. Berven, MD,4 and Dean Chou, MD1

Departments of 1Neurological Surgery and 2Orthopedic Surgery, UCSF Spine Center, University of California, San Francisco, California

• 99 patients retrospective analysis
  • 27 were in the FC group
  • 46 in the Lower thoracic to sacrum group
  • 26 in the Upper thoracic to sacrum group.

• FC >10 degrees, radiculopathy on concavity of the curves

• Patients were considered to be well aligned if their SVA was < 5 cm, their PT was < 20°, and the difference between their PI and LL was < 10°.

<table>
<thead>
<tr>
<th>TABLE 1. Summary of preoperative patient characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
</tr>
<tr>
<td>No. of patients</td>
</tr>
<tr>
<td>FU in mce</td>
</tr>
<tr>
<td>Average age in yrs</td>
</tr>
<tr>
<td>No. of males (%)</td>
</tr>
<tr>
<td>BMI in kg/m²</td>
</tr>
<tr>
<td>ASA physical status, no. of patients</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>Prior non-kyphotic spine op, no. of patients (%)</td>
</tr>
<tr>
<td>Preop spine imaging characteristics</td>
</tr>
<tr>
<td>FC in °</td>
</tr>
<tr>
<td>PI in °</td>
</tr>
<tr>
<td>PT in °</td>
</tr>
<tr>
<td>LL in °</td>
</tr>
<tr>
<td>PI-LL mismatch in °</td>
</tr>
<tr>
<td>SVA in cm</td>
</tr>
<tr>
<td>Coronal balance magnitude in cm</td>
</tr>
<tr>
<td>Sacral slope major curve in °</td>
</tr>
<tr>
<td>Well-aligned spine, no. of patients (%)</td>
</tr>
</tbody>
</table>
Amara et al.

**TABLE 2. Summary of surgical characteristics**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Total</th>
<th>FC</th>
<th>LT</th>
<th>UT</th>
<th>p Value*</th>
<th>FC vs LT p Value</th>
<th>FC vs UT p Value</th>
<th>UT vs LT p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>99</td>
<td>27</td>
<td>46</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procedure duration in mins</td>
<td>426</td>
<td>421</td>
<td>454</td>
<td>383</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated blood loss in ml</td>
<td>1753</td>
<td>592</td>
<td>1950</td>
<td>2634</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.22</td>
</tr>
<tr>
<td>Length of hospital stay in days</td>
<td>7.5</td>
<td>5.5</td>
<td>8.3</td>
<td>8.3</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.99</td>
</tr>
<tr>
<td>Interbody device at FC, no. of patients (%)</td>
<td>78 (78.8)</td>
<td>25 (92.6)</td>
<td>36 (78.3)</td>
<td>17 (65.4)</td>
<td>0.051</td>
<td>0.19</td>
<td>0.019</td>
<td>0.27</td>
</tr>
<tr>
<td>Laminectomy at FC, no. of patients (%)</td>
<td>64 (64.6)</td>
<td>19 (70.4)</td>
<td>32 (60.6)</td>
<td>13 (50)</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Boldface type indicates statistical significance.

*The p value from comparing all three groups using the ANOVA, chi-square, or Fisher exact test, depending on whether the variable was continuous or categorical and on the sample size. If the overall test yielded p < 0.1, pairwise tests were done to detect specific differences between groups.

**TABLE 4. Extension indications and fusions**

<table>
<thead>
<tr>
<th>Case No</th>
<th>Op Group</th>
<th>Extension Indication</th>
<th>Extension Fusion</th>
<th>Time to Extension (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FC</td>
<td>Progressive deformity, significant pain above fusion</td>
<td>T10-S1</td>
<td>742</td>
</tr>
<tr>
<td>2</td>
<td>FC</td>
<td>Pseudarthrosis secondary to smoking</td>
<td>L3-S1*</td>
<td>425</td>
</tr>
<tr>
<td>3</td>
<td>FC</td>
<td>Progressive deformity, pain above fusion</td>
<td>T10-S1</td>
<td>422</td>
</tr>
<tr>
<td>4</td>
<td>FC</td>
<td>Adjacent level degeneration w/ stenosis, progressive back/radiculopathy</td>
<td>T11-S1</td>
<td>960</td>
</tr>
<tr>
<td>5</td>
<td>FC</td>
<td>Progressive pain, radiculopathy</td>
<td>T3-S1</td>
<td>387</td>
</tr>
<tr>
<td>6</td>
<td>FC</td>
<td>Progressive deformity, adjacent segment degeneration</td>
<td>T12-S1</td>
<td>2806</td>
</tr>
<tr>
<td>7</td>
<td>FC</td>
<td>Progressive deformity, adjacent segment stenosis</td>
<td>T10-S1</td>
<td>1886</td>
</tr>
<tr>
<td>8</td>
<td>LT</td>
<td>PKJ</td>
<td>T3-S1</td>
<td>259</td>
</tr>
<tr>
<td>9</td>
<td>LT</td>
<td>Progressive deformity, pseudarthrosis, broken implants</td>
<td>T9-S1</td>
<td>1414</td>
</tr>
<tr>
<td>10</td>
<td>LT</td>
<td>PKJ</td>
<td>T3-S1</td>
<td>511</td>
</tr>
<tr>
<td>11</td>
<td>LT</td>
<td>Proximal junctional stenosis &amp; failure</td>
<td>T4-S1</td>
<td>26</td>
</tr>
<tr>
<td>12</td>
<td>LT</td>
<td>PKJ</td>
<td>T3-S1</td>
<td>560</td>
</tr>
<tr>
<td>13</td>
<td>LT</td>
<td>PKJ</td>
<td>T4-S1</td>
<td>1800</td>
</tr>
<tr>
<td>14</td>
<td>UT</td>
<td>Cervicothoracic kyphosis, PKJ</td>
<td>C2-S1</td>
<td>1147</td>
</tr>
</tbody>
</table>

*Including new pelvic fixation.

- Higher incidence of PI-LL mismatch in FC subgroup than in the LT and UT groups
Conclusions

• Fractional curve, although compensatory, must be adequately assessed when planning adult deformity surgery
• Can be a focal and significant cause of low back and radicular pain
• Treatment isolated to the fractional curve can be successful but is associated with a higher incidence of fusion extension in the intermediate term
• Best patients are likely unilateral radiculopathy on the concavity of the FC, no significant mismatch in spinal parameters, high risk patients (frail, elderly, comorbidities).
Disclosures

- Consultant
  - Depuy Spine, Alphatec, Stryker/K2M, Surgalign, SpineArt, Restor3D, CarboFix, Icotec

- Research support
  - NIH/NHS/CDMI

- Surgeon Advisory Board
  - Ulrich Medical USA, Restor3D

- Educational content development
  - JBJS Inc.
Background
Extradural Tumors

Goals of this talk
1) Pre-op Considerations
2) General principles of resection
   • Spinal Location
3) Reconstructive Options

What We Will Not Cover
1) Differential diagnoses
2) Indication for operations

Pre-Op Planning
Covering All the Bases

1) Labs
   • CBC w/diff, BMP, LFTs, Coags, ESR, CRR, Albumin

2) Bilateral LE ultrasounds (DVTs)
   • If (+) → IVC filter placement

3) Fiducial marker placement
   1) Thoracic tumors
   2) Pedicle above/below level of resection

4) Angiogram/Embolization
   • Optimize chances of minimizing blood loss
   • Assess artery of Adamkiewicz

Resection Principles
(Mobile Spine)
Primary Tumors

* Resection (en-bloc) questions aimed at achieving negative margins

1) Which Approach?

2) How many levels? (Discectomies?)

Which Approach?

* Weinstein-Boriani-Biagini (WBB) surgical system
Where to cut discs?

- Evaluate Sagittal Images

Zone 4-9 = Posterior → Anterior

Anterior (large soft tissue component)
Case Examples

- 60-year old male with mild mid back pain
- Biopsy: T9 Rhabdomyosarcoma (grade 2)
- Neoadjuvant radiation → tumor growth
- Plan?
Unilateral (Zones 1-6 or 7-12) = Posterior → Anterior

Zone 3-10 = Posterior Only
15 yo spindle cell sarcoma

Discectomies?

T4 + T5 Lesion
T3-4 and T5-6 discs
Special Considerations

- Cervicothoracic/upper thoracic tumors

Metastatic Disease Resection Principles (Mobile spine)
Invasiveness?

- Posteriorly-based met
- Ventral met
  - Mechanical instability predominant with no/ minimal ventral neural compression
  - Preserved sagittal alignment (no kyphosis)
  - Prior radiation
  - Limited life expectancy

- Ventral met w/cord compression
- Kyphosis
- "Radioresistant" tumor w/no prior radiation
- Prior radiation and tumor enlarging

Utility of expanded anterior column resection versus decompression-alone for local control in the management of carcinomatous vertebral column metastases undergoing adjuvant stereotactic radiotherapy.


(p=0.03). Only tumor pathology predicted time to local recurrence (p<0.01), though inspection of Kaplan-Meier functions showed superior long-term local control in patients with radiosensitive tumor pathologies, no previous irradiation of the metastasis, and who underwent anterior column resection versus epidural removal alone. Median time to recurrence was 288 days with 100% of lesions showing anterior column recurrence and recurrence in the epidural space.

CONCLUSIONS: With the increasing shift towards surgery as a neoadjuvant to radiotherapy for patients with spinal column metastases, the role for surgical debulking has become less clear. In the present study, we find that anterior column debulking as opposed to epidural debulking-alone decreases the odds of local recurrence and improves long-term local control. © 2021 Elsevier Inc. All rights reserved.
Thoracic Mets - Approach

T3 + T4: Met Lung Cx

Posterior

(2-level VCR)

Anterior

(thoracotomy)
1) Place stabilizing rod on 1 side before doing laminectomy

2) Clamp nerves/arteries unilaterally for 10 mins (q1 min MEPs)
3) Sacrifice nerves proximal to DRG with 2-0 silk ties and repeat clamping/q1 min MEPs on contralateral side

4) To access most distal disc may have to remove distal rib head
Lumbar Mets - Approach

L3: Met Breast Cx

Posterior only (lami+PSF; No Corp)
Reconstruction

Anterior Column Reconstruction

Posterior Column Reconstruction

Structural Support

Screws
- Material
- Approach (open vs. perc)

Rods
- Material
- Number

Modularity
Anterior Column Reconstruction

- Cage
  - PMMA
  - Osseous
  - Radiolucent
  - Metallic

+ Cage

Modularity of Cage

- Static
- Expandable
- Circular
- Rectangular
Posterior Column Stabilization

<table>
<thead>
<tr>
<th>Pedicle Screws</th>
<th>Rods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic</td>
<td>Metallic</td>
</tr>
<tr>
<td>Radiolucent</td>
<td>Radiolucent</td>
</tr>
<tr>
<td>Titanium/CoCr</td>
<td>Carbon Fiber</td>
</tr>
</tbody>
</table>

- Open
  - Neural decompression
- Perc
  - Only stabilization needed

*** No corpectomy = 2 ***
*** Corpectomy = 3 or 4 ***
My Practice...In Evolution

T9 Leiomyosarcoma (en-bloc)

Generation 1
All metallic

Generation 2
Anterior column: metallic
Rods: metallic
Posterior column: metallic
Screws: metallic

Metastatic lung cancer (2-level VCR)
My Practice...In Evolution

**Generation 3**

**Anterior column**
Radiolucent

**Posterior column**

* Screws: all metallic except adjacent to corpectomy, which are radiolucent
* Rods: metallic

Metastatic breast cancer (1-level VCR)

**Generation 4**

**Anterior column**
Radiolucent

**Posterior column**

* Screws: all metallic except adjacent to corpectomy, which are radiolucent
* Rods: radiolucent

Spindle cell sarcoma (15yo; 2-level en-bloc)
Soft Tissue Coverage

VRAM
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

* Keystone
* Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?

$S_3$ and Above
Anterior → Posterior

Below $S_2$
Posterior-only

Keystone
Unilateral pedicled superior gluteal artery

Soft Tissue Coverage

Vented Rectus Abdominis Muscle (VRAM)
Local vs. free flap

Approach?
Lumbopelvic Stabilization

Below S3
No stabilization required

S3 and Above
Stabilization bc SI joint disrupted
Posterior Pelvic Ring Stabilization

Fig. 13.3 Posterior pelvic ring fixation (PPRF) methods. (a) Triangular frame reconstruction (TFR). (b) Johns Hopkins Hospital (JHH) method.

Anterior Column Support

Fig. 13.4a–c Anterior spinal column fixation (ASCF) combined with SPF and PPRF. (a) Novel reconstruction (NR), (b) Bilateral fibular graft technique (BFFR). (c) Modified bilateral fibular graft technique (mBFFR).
Case #1

56-year old female; chordoma; no mets
Negative Margins

Case #2

67 year old male; healthy, chordoma; no mets
Case #3

24yo M  
Osteosarcoma  
No mets
Sacral Mets
Perc stabilization
Multiple Myeloma
Finito!
Correction strategies in Pediatric Scoliosis

Yashar Javidan, MD
Associate Professor
Spine Fellowship Director
University of California Davis & Shriners Hospital North Cal
Dep. Orthopaedic Surgery

Disclosures: None

Current Disclosure Summary

- Alphatec Spine: IP royalties; Paid consultant; Stock or stock Options
- AO Spine: Paid presenter or speaker; Fellowship Support
- Johnson & Johnson: Paid consultant
- NuVasive: Paid consultant
- Stryker/K2M: Paid consultant; Stock or stock Options
AIS: derotation

Derotation: The Big Picture

Rotate convex “rib hump” medial and anterior.

Solution:

- Multilevel linked derotators (made by multiple companies) to disperse the force of apical derotation
Apical Vertebral Derotation

- Augments frontal curve correction
- Achieves a more predictable centralization of trunkal balance
- Saves lumbar motion segments
- Has demonstrated an acceptable safety margin to date
12+1 F AIS, (6mon post menarche) progressed over past 2.5 years
Chiropractor was treating the curve with manipulation
Normal MRI

Exam:
Mild back & scapular pain
Right trunk shift
Neurologic exam: Normal

Plan: Anterior release; T3-L3 PSF
Rod bending

Rod reduction & global derotation
Segmental Derotation
Decortication and bone grafting
Case Information

2019 Dashboard

- The following slides contain data from patients submitted in 2019.
- In graphs, green bars and scatter plots represent your data and blue bars represent the group as a whole.

<table>
<thead>
<tr>
<th></th>
<th>You</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>11</td>
<td>1366</td>
</tr>
</tbody>
</table>
Pre/1st Erect Major Cobb Summary

YOU (all pts)

<table>
<thead>
<tr>
<th></th>
<th>Pre-Op Curve</th>
<th>Post-Op Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td>60</td>
<td>9</td>
</tr>
<tr>
<td>StdDev</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Min</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>Max</td>
<td>70</td>
<td>23</td>
</tr>
</tbody>
</table>

GROUP (all pts)

<table>
<thead>
<tr>
<th></th>
<th>Pre-Op Curve</th>
<th>Post-Op Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td>60</td>
<td>18</td>
</tr>
<tr>
<td>Smallest Avg</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>Largest Avg</td>
<td>77</td>
<td>35</td>
</tr>
</tbody>
</table>

Pre/1st Erect T5-T12 Kyphosis (deg)

YOU (all pts)

<table>
<thead>
<tr>
<th></th>
<th>Pre-Op Kyphosis</th>
<th>Post-Op Kyphosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td>29</td>
<td>36</td>
</tr>
<tr>
<td>StdDev</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>Min</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td>Max</td>
<td>44</td>
<td>45</td>
</tr>
</tbody>
</table>

GROUP (all pts)

<table>
<thead>
<tr>
<th></th>
<th>Pre-Op Kyphosis</th>
<th>Post-Op Kyphosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td>Smallest Avg</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>Largest Avg</td>
<td>38</td>
<td>36</td>
</tr>
</tbody>
</table>
### Pre/1st Erect T12-S1 Lordosis (deg)

#### YOU (all pts)

<table>
<thead>
<tr>
<th></th>
<th>Pre-Op Lordosis</th>
<th>Post-Op Lordosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td>50</td>
<td>49</td>
</tr>
<tr>
<td>StdDev</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Min</td>
<td>37</td>
<td>30</td>
</tr>
<tr>
<td>Max</td>
<td>65</td>
<td>75</td>
</tr>
</tbody>
</table>

#### GROUP (all pts)

<table>
<thead>
<tr>
<th></th>
<th>Pre-Op Lordosis</th>
<th>Post-Op Lordosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td>54</td>
<td>50</td>
</tr>
<tr>
<td>Smallest Avg</td>
<td>23</td>
<td>35</td>
</tr>
<tr>
<td>Largest Avg</td>
<td>65</td>
<td>62</td>
</tr>
</tbody>
</table>

---

**DB Summary**
Less Invasive – Lateral Lumbar Interbody Fusion and Lateral ALIF

UCSF Pediatric and Adult Spine Surgery Course
July 16, 2022

Aaron J Clark, MD, PhD
Associate Professor
Department of Neurological Surgery
University of California, San Francisco

Disclosures

- Nuvasive – consultant, grant funding
- Alphatec - consultant
History of ALIF – anterior approaches

- 1906 – Muller
  - Transperitoneal approach to TB of the lumbar spine
- 1928 – Royle
  - Retroperitoneal approach to congenital hemivertebra of the lumbar spine
- 1933 – Chaklin
  - Retroperitoneal approach for lumbar osteotomy

History of ALIF - fusion

- 1933 – Burns
  - First anterior lumbar fusion
  - Spondylolisthesis
- 1944 – Iwahara
  - ALIF for degenerative disc disease - retroperitoneal
- 1948 – Lane and Moore
  - ALIF for degenerative disc disease – transperitoneal
- 1997 – Ray
  - Threaded cages

Advantages of ALIF

- No neural retraction
- Improved ability to restore;
  - Lordosis
  - Disc height
  - Foraminal height

Importance of L4-S1

Barrey et al., 2015
Risk stratification for ALIF: Obesity

UCSF ALIF database

- 2007-2016
- Retrospective
- 938 patients
- All exposures by Vascular Surgery

- Patient demographics
  - Obesity = BMI >= 30
- Surgical details
- Complications
  - Intraoperative
  - Postoperative

Complications in detail

- Intraoperative
  - Arterial
  - Venous
  - Ureteral
  - Bowel
- Postoperative
  - Ileus
  - Wound
  - Neurologic
  - Medical
    - Cardiac
    - Pulmonary
    - Urologic
    - Renal
    - Vascular
Demographics

- High percentage of obese patients
- Majority have had prior surgery
- Degenerative processes most common

Surgical details

- 2 level ALIF most common
- Transthoracic – higher levels
- Different group
- Majority get posterior supplementation

Overall complications

- Relatively high complication rate
  - Driven by postop complications
  - Long follow up

Patient demographics and complications

- Increasing complications with:
  - Older age
  - Higher BMI
  - Obesity
  - Deformity
  - Infection
Similar characteristics for obese and nonobese ALIF patients (n=898)

- Higher BMI (obviously)
- More co-morbidities
- More diabetics
- Slightly less deformity

Increased complications when obese

- Higher complication rate
- Driven by postop complications
- Mostly ileus and wound healing problems

Complications not affected by severity of obesity

- Trend toward more hematomas
- Trend toward more DVT
BMI threshold for increased complications

Conclusions about obesity and ALIF

- Patients with a BMI $\geq 31$ have significantly increased risk of complications
- Complications are mostly postoperative
- Obese patients should be counseled
- Particular attention should be paid to wound healing
- Consider lateral positioning

Operating on the laterally positioned patient

Incision location and dissection

- Muscle splitting
- Possibly less hernia
- Possibly less pseudo hernia
Wide exposure of the disc space

- Less peritoneal retraction
- Possibly less ileus

Midline cage placement

Lateral Lumbar Interbody Fusion

Multicenter assessment of surgical outcomes in adult spinal deformity patients with severe global coronal malalignment: determination of target coronal realignment threshold.


Conclusions: Study results demonstrated that ASD surgery in patients with substantial OCM was associated with significant radiographic and HRQOL improvement despite high complication rates. MCD improvement was highest for SRS-22® Appearance/Self-Image. Absolute OCM ≥7 cm was associated with a worse outcome suggesting a potential coronal realignment target threshold to assist surgical planning.
Coronal imbalance in degenerative lumbar scoliosis: Prevalence and influence on surgical decision-making for spinal osteotomy.

- Less reliably corrected (Type C)
- Preop coronal malalignment due to a trunk shift ipsilateral to apex of degen thoracolumbar scoliosis
- 60% persistent malalignment

Table 2: Preoperative radiographic parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean SD</td>
<td>Mean SD</td>
<td>Mean SD</td>
<td></td>
</tr>
<tr>
<td>Preoperative</td>
<td>After LIF</td>
<td>After PST+</td>
<td>Last follow-up</td>
</tr>
<tr>
<td>Lower rib-off (mm)</td>
<td>10.4±4.5</td>
<td>15.4±6.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pelvis (mm)</td>
<td>23.2±3.7</td>
<td>22.9±3.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>AS (mm)</td>
<td>22.3±5.9</td>
<td>22.3±5.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lower rib-off (mm)</td>
<td>38.6±9.5</td>
<td>41.6±9.6</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

The role of the fractional lumbosacral curve in persistent coronal malalignment following adult thoracolumbar deformity surgery: a radiographic analysis

- Retrospective review (2008-2014)
- Thoracolumbar scoliosis
- Primary Operations
- 124 patients (divided based on Bao classification)
  - Type A: 87
  - Type B: 19
  - Type C: 18
Comparative analysis of 3 surgical strategies for adult spinal deformity with mild to moderate sagittal imbalance

<table>
<thead>
<tr>
<th>Procedure</th>
<th>LLIF-PVP</th>
<th>ALIF-PVP</th>
<th>PVP Only</th>
<th>( p ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobb angle</td>
<td>1.7°</td>
<td>2.5°</td>
<td>2.8°</td>
<td>0.006</td>
</tr>
<tr>
<td>Lumbar lordosis</td>
<td>56.7</td>
<td>57.3</td>
<td>56.8</td>
<td>0.019</td>
</tr>
<tr>
<td>QOL</td>
<td>43.6</td>
<td>57.4</td>
<td>44.2</td>
<td>0.027</td>
</tr>
</tbody>
</table>

Utility of multilevel lateral interbody fusion of the thoracolumbar coronal curve apex in adult deformity surgery in combination with open posterior instrumentation and LS-SI interbody fusion: a case-matched evaluation of 32 patients

<table>
<thead>
<tr>
<th>Procedure</th>
<th>LLIF-PVP</th>
<th>ALIF-PVP</th>
<th>PVP Only</th>
<th>( p ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td>50.4</td>
<td>58.1</td>
<td>60.4</td>
<td>0.008</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>42.6</td>
<td>44.4</td>
<td>41.7</td>
<td>0.073</td>
</tr>
</tbody>
</table>

**Note:** Boldface type indicates statistical significance.
Advantages of LLIF

- Improved surface area for fusion
- Release of contralateral annulus/osteophyte
- Indirect decompression
Coronal balance with circumferential minimally invasive spinal deformity surgery for the treatment of degenerative coronal imbalance: are we heading in the right direction?

Corey L. Weber, MD; Jay S. Smith, MD; Srinivas Angel, MD; Peter Grenier, MD; Amy D. Turner, MS; Phil Warkol, MD

TABLE 2: Surgical data for patients according to their coronal alignment subgroup

<table>
<thead>
<tr>
<th>Coronal Alignment Subgroup</th>
<th>Data</th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td></td>
<td>29</td>
<td>11</td>
<td>6</td>
<td>46</td>
</tr>
<tr>
<td>ALIF, L5–S1</td>
<td></td>
<td>11</td>
<td>4</td>
<td>6</td>
<td>21</td>
</tr>
<tr>
<td>Uneven segments fused</td>
<td></td>
<td>4.4</td>
<td>6.4</td>
<td>3.4</td>
<td>4.9</td>
</tr>
<tr>
<td>Lung segment—tends to sacrum fixation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACR4</td>
<td></td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Prior fusion</td>
<td></td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Dextroscoliosis/levescoliosis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median curve apex</td>
<td></td>
<td>12–3 disc</td>
<td>15–2 disc</td>
<td>17–2 disc</td>
<td>17–2 disc</td>
</tr>
<tr>
<td>ThoracicSIM</td>
<td></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

*Codes are expressed as the number of patients unless otherwise indicated. Type A patients had no CME; type B patients had a progressive shift toward the concavity; and type C patients had a progressive shift toward the convexity.*
LLIF - Conclusions

• Type C curves are at risk of undercorrection

• Addition of LLIF can be beneficial for correction coronal and sagittal imbalance

• LLIF may not adequately correct Type C curves

• Minimally invasive lateral release may allow more ability for correction

• Additional research is needed