UCSF
Pediatric and Adult Spine Course

August 4-7, 2021
Royal Hawaiian Resort
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

Stryker/K2M

ZimmerBiomet
Exhibitors

ATEC Spine
Amplify Surgical
Bioventus
DePuy Synthes Spine
Evolution Spine
Globus Medical
Golden Gate Surgical
Kurosbio
Medacta
Medtronic
Nuvasive
Orthofix
Orthopediatrics Corp
Pacira
Si-Bone
Stryker/K2M
The Queen’s Health System
Ventris Medical
ZimmerBiomet
UCSF Pediatric and Adult Spine 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

An attendee completing this course 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
Accreditation

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.

UCSF designates this educational activity for a maximum of 25.00 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 category 1 credit for the PRA for organizations accredited by the ACCME.

Pharmacy
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, August 4th, you should have received 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, August 7th, 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.
General Information

Luau Reception
We are pleased to host the Luau Reception on Wednesday, August 4th starting at 6:10PM at the Azure Restaurant.

Lunch
On Thursday, August 4th and Friday, August 5th, 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 Chairs

Lionel N. Metz, MD  
Assistant Professor of Orthopaedic Surgery  
University of California, San Francisco

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

Lee Tan, MD  
Assistant Professor in Residence, Department of Neurological Surgery

Honored Speakers

Lawrence G. Lenke, MD  
Professor of Orthopedic Surgery with Tenure Chief; Division of Spinal Surgery  
Chief of Spinal Deformity Surgery, Columbia University Medical Center College of Physicians and Surgeons  
Surgeon-in-Chief Daniel and Jane Och Spine Hospital, New York, NY

K. Daniel Riew, MD  
Associate Professor of Orthopedic Surgery in Neurological Surgery  
Och Spine Hospital, Weill Cornell Medical Center, New York, New York

Amer Samdani, MD  
Chief of Surgery, Shriners Hospitals for Children, Philadelphia, PA

Course Faculty

(University of California, San Francisco unless indicated)

Sigurd H. Berven, MD  
Professor of Orthopaedic Surgery Chief of Spine Service

Shane Burch, MD  
Professor of Orthopaedic Surgery

J. Matthew Cage, DO  
Assistant Professor of Surgery, Uniformed Services University of the Health Sciences  
Residency Director, Department of Orthopaedic Surgery, Tripler Army Medical Center, Honolulu, Hawaii

Aaron Clark, MD, PhD  
Assistant Professor Neurosurgery

Graham Fedorak, MD  
Pediatric Orthopedics, Kapiolani Medical Center for Women & Children, Honolulu, HI

Stephen George, MD  
Professor of Neurological Surgery; Chief, Division of Pediatric Neurosurgery

Sina Pourathei, MD  
Spine Surgeon, Gulf Coast Orthopaedics, Houma, Louisiana
**Course Faculty**
(all UCSF unless indicated)

**Thomas Noh, MD**
Private Practice Neurosurgeon, Straub Hospital, Honolulu, HI

**David L. Skaggs, MD, MMM**
Chief of Orthopaedic Surgery, Director of Spine Surgery, Endowed Chair of Pediatric Spinal Disorders
Attending Physician, Professor of Surgery, Keck School of Medicine of USC Los Angeles, CA

**Peter Sun, MD**
Director, Pediatric Neurosurgery, UCSF Benioff Children's Hospital, Oakland, CA

**Alekos Theologis, MD**
Assistant Professor of Orthopaedic Surgery

**Alexander Tuchman, MD**
Department of Neurology and Neurosurgery, Cedar-Sinai, Los Angeles, CA
The following faculty speakers, moderators and planning committee members have disclosed NO financial interest/arrangement or affiliation with any commercial companies who have provided products or services relating to their presentation(s) or commercial support for this continuing medical education activity:

Alexander Tuchman, MD  Peter Sun, MD
Graham Fedorak, MD  Sina Pourtaheri, MD
Kyle Mitsunaga, MD  Thomas Noh, MD
Matthew Cage, MD

The following faculty speakers have disclosed a financial interest/arrangement or affiliation with a commercial company who has provided products or services relating to their presentation(s) or commercial support for this continuing medical education activity. All conflicts of interest have been resolved in accordance with the ACCME Standards for Commercial Support.

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aaron Clark, MD</td>
<td>Nuvasive</td>
<td>Grant/Research Support, Consultant</td>
</tr>
<tr>
<td>Alekos Theologis, MD</td>
<td>DePuy</td>
<td>Consultant, Royalties/Holder of Intellectual Property Rights</td>
</tr>
<tr>
<td></td>
<td>Alphatec Spine</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>Stryker/K2M</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>Ulrich</td>
<td>Consultant</td>
</tr>
<tr>
<td>Amer Samdani, MD</td>
<td>Zimmer Biomet</td>
<td>Royalties/Holder of Intellectual Property Rights, Consultant</td>
</tr>
<tr>
<td></td>
<td>Nuvasive</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>DePuy Synthes</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>Stryker/K2M</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>Ethicon</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>Globus</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>Mirius</td>
<td>Consultant</td>
</tr>
<tr>
<td>David Skaggs, MD</td>
<td>Evolution Spine</td>
<td>Royalties/Holder of Intellectual Property Rights, Consultant</td>
</tr>
<tr>
<td>Emmanuel Menga, MD</td>
<td>Globus Medical</td>
<td>Consultant, Honorarium Recipient</td>
</tr>
<tr>
<td>K Daniel Riew, MD</td>
<td>Zimmer Biomet</td>
<td>Royalties/Holder of Intellectual Property Rights, Consultant</td>
</tr>
<tr>
<td></td>
<td>Nuvasive</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>Happe Spine</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>Axiomet</td>
<td>Stock Shareholder (excluding mutual funds)</td>
</tr>
<tr>
<td></td>
<td>Expanding Orthopedics</td>
<td>Stock Shareholder (excluding mutual funds)</td>
</tr>
<tr>
<td></td>
<td>Spinal Kinetics</td>
<td>Stock Shareholder (excluding mutual funds)</td>
</tr>
<tr>
<td></td>
<td>Amedico</td>
<td>Stock Shareholder (excluding mutual funds)</td>
</tr>
<tr>
<td></td>
<td>Vertiflex</td>
<td>Stock Shareholder (excluding mutual funds)</td>
</tr>
<tr>
<td></td>
<td>Benvenue</td>
<td>Stock Shareholder (excluding mutual funds)</td>
</tr>
<tr>
<td></td>
<td>Paradigm Spine</td>
<td>Stock Shareholder (excluding mutual funds)</td>
</tr>
<tr>
<td></td>
<td>NASS</td>
<td>Board Member</td>
</tr>
</tbody>
</table>

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.
The following faculty speakers have disclosed a financial interest/arrangement or affiliation with a commercial company who has provided products or services relating to their presentation(s) or commercial support for this continuing medical education activity. All conflicts of interest have been resolved in accordance with the ACCME Standards for Commercial Support:

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lawrence Lenke, MD</td>
<td>Medtronic</td>
<td>Royalties/Holder of Intellectual Property Rights, Consultant</td>
</tr>
<tr>
<td></td>
<td>Acuity Surgical</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>Abyx</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>AO Spine</td>
<td>Grant/Research Support</td>
</tr>
<tr>
<td>Lee Tan, MD</td>
<td>Medtronic</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>Stryker</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>Integrity Implants</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>Globus</td>
<td>Consultant</td>
</tr>
<tr>
<td>Lionel Metz MD</td>
<td>Evolution Spine</td>
<td>Consultant,Royalties/Holder of Intellectual Property Rights</td>
</tr>
<tr>
<td>Shane Burch, MD</td>
<td>Medtronic</td>
<td>Consultant</td>
</tr>
<tr>
<td></td>
<td>NuVAsive</td>
<td>Employee</td>
</tr>
<tr>
<td>Sigurd Berven, MD</td>
<td>Medtronic</td>
<td>Advisor or Reviewer,Consultant,Honorarium Recipient</td>
</tr>
<tr>
<td></td>
<td>Stryker</td>
<td>Advisor or Reviewer,Consultant,Honorarium Recipient</td>
</tr>
<tr>
<td></td>
<td>Innovasis</td>
<td>Advisor or Reviewer,Consultant,Honorarium Recipient</td>
</tr>
<tr>
<td></td>
<td>Globus</td>
<td>Board Member,Consultant,Stock Shareholder (excluding mutual funds),Honorarium Recipient</td>
</tr>
<tr>
<td></td>
<td>Camber spine</td>
<td>Advisor or Reviewer,Consultant,Honorarium Recipient</td>
</tr>
<tr>
<td></td>
<td>integrity</td>
<td>Advisor or Reviewer,Consultant,Honorarium Recipient</td>
</tr>
<tr>
<td>Stephen George, MD</td>
<td>Stryker/K2M</td>
<td>Consultant</td>
</tr>
</tbody>
</table>

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.
# COURSE PROGRAM

## Wednesday, August 4, 2021

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:00pm</td>
<td>Registration</td>
<td></td>
</tr>
<tr>
<td>3:15</td>
<td>Welcome and Introductions</td>
<td>Lionel Metz MD, Lee Tan, MD, Kyle Mitsunaga MD</td>
</tr>
<tr>
<td>3:20</td>
<td>Honored Speaker Introduction</td>
<td></td>
</tr>
<tr>
<td>3:25</td>
<td>Cervical Spondylotic Myelopathy: Anterior, Posterior, or Both</td>
<td>K Daniel Riew, MD-01</td>
</tr>
<tr>
<td>3:55</td>
<td>Upper Cervical Instability and Stenosis in Pediatric Population</td>
<td>Peter Sun, MD-02</td>
</tr>
<tr>
<td>4:15</td>
<td>Pediatric Spondylolisthesis: Approach Choice and Importance of Reduction</td>
<td>Sigurd Berven, MD-03</td>
</tr>
<tr>
<td>4:35</td>
<td>Honored Speaker Introduction</td>
<td></td>
</tr>
<tr>
<td>4:40</td>
<td>Pediatric Spine Tethering: Indications, Pitfalls, Lessons Learned</td>
<td>Amer Samdani, MD-04</td>
</tr>
<tr>
<td>5:10</td>
<td>Case Presentation and Discussion</td>
<td></td>
</tr>
<tr>
<td>5:40</td>
<td>Q&amp;A</td>
<td></td>
</tr>
<tr>
<td>6:00pm</td>
<td>Adjourn: Luau Reception in the Azure Restaurant</td>
<td></td>
</tr>
</tbody>
</table>

## Thursday, August 5, 2021

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00am</td>
<td>Continental Breakfast</td>
<td></td>
</tr>
<tr>
<td>7:30</td>
<td>Opiate Use, Abuse, and Dependency Prevention in Spine Surgery</td>
<td>Sina Pourtaheri, MD-05</td>
</tr>
<tr>
<td>8:00</td>
<td>Honored Speaker Introduction</td>
<td></td>
</tr>
<tr>
<td>8:05</td>
<td>Posterior VCR for Severe Pediatric Deformity, Tips, Tricks, Alternatives</td>
<td>Lawrence Lenke, MD-06</td>
</tr>
<tr>
<td>8:45</td>
<td>Correction of AIS</td>
<td></td>
</tr>
<tr>
<td>9:15</td>
<td>Case Presentation and Discussion</td>
<td></td>
</tr>
<tr>
<td>9:45</td>
<td>Q&amp;A</td>
<td></td>
</tr>
<tr>
<td>10:10</td>
<td>Coffee Break</td>
<td></td>
</tr>
<tr>
<td>10:30</td>
<td>Less Invasive Lumbar Interbody Fusion LLIF, lateral ALIF</td>
<td>Aaron Clark, MD-08</td>
</tr>
<tr>
<td>11:00</td>
<td>Essentials of Resection and Reconstruction for Tumors of the Spinal Column</td>
<td>Alekos Theologis, MD-09</td>
</tr>
<tr>
<td>11:30</td>
<td>Q&amp;A and Case Discussion</td>
<td></td>
</tr>
<tr>
<td>12:00 pm</td>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td>1:00</td>
<td>Use of Technologies in Pediatric Scoliosis Surgery</td>
<td>David Skaggs, MD-10</td>
</tr>
<tr>
<td>1:30</td>
<td>Conservative Management of Early-Onset Scoliosis – Things I've Learned About Mehta Casting and Why Starting Early Matters</td>
<td>Graham Fedorak, MD-11</td>
</tr>
<tr>
<td>1:50</td>
<td>Honored Speaker Introduction</td>
<td></td>
</tr>
<tr>
<td>1:55</td>
<td>Cervical Deformity: Assessment and Reconstructive Options</td>
<td>K Daniel Riew, MD-12</td>
</tr>
<tr>
<td>2:20</td>
<td>Q&amp;A and Case Discussion</td>
<td></td>
</tr>
<tr>
<td>2:40</td>
<td>Case Presentations (Fellows)</td>
<td></td>
</tr>
<tr>
<td>3:00 pm</td>
<td>Adjourn</td>
<td></td>
</tr>
</tbody>
</table>
### Friday, August 6, 2021

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00am</td>
<td>Continental Breakfast</td>
</tr>
<tr>
<td>7:30am</td>
<td>Cadaver Lab</td>
</tr>
<tr>
<td>11:30am</td>
<td>Lunch</td>
</tr>
<tr>
<td>12:30pm</td>
<td>Cadaver Lab</td>
</tr>
<tr>
<td>4:30pm</td>
<td>Adjourns</td>
</tr>
</tbody>
</table>

**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, August 7, 2021

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00am</td>
<td>Continental Breakfast</td>
</tr>
<tr>
<td>7:30</td>
<td>Deciding When to Use 3 Column Osteotomies vs Multiple Posterior Column Osteotomies for Deformity Correction Alexander Tuchman, MD-13</td>
</tr>
<tr>
<td>7:50</td>
<td>Honored Speaker Introduction</td>
</tr>
<tr>
<td>7:55</td>
<td>Complication Avoidance in Neuromuscular Scoliosis                     Amer Samdani, MD-14</td>
</tr>
<tr>
<td>8:25</td>
<td>Update on Biological Adjuvants in Spinal Fusion                       Kyle Mitsunaga, MD-15</td>
</tr>
<tr>
<td>8:45</td>
<td>Implant Density in AIS Fusion Constructs                              Matthew Cage, MD-16</td>
</tr>
<tr>
<td>9:05</td>
<td>Augmented Reality in Spine Surgery                                    Thomas Noh, MD-17</td>
</tr>
<tr>
<td>9:25</td>
<td>Q &amp; A and Case Discussion</td>
</tr>
<tr>
<td>9:55</td>
<td>Break</td>
</tr>
<tr>
<td>10:15</td>
<td>PJK Etiology, Risk Factors, and Prevention                            Emmanuel Menga, MD-18</td>
</tr>
<tr>
<td>10:35</td>
<td>Surgical Navigation in Spine Reconstructive Surgery, Uses Anteriorly and Posteriorly Shane Burch, MD-19</td>
</tr>
<tr>
<td>10:55</td>
<td>Honored Speaker Introduction</td>
</tr>
<tr>
<td>11:00</td>
<td>Posterior Only Adult Reconstruction: Strategies to Obtain Optimal Results Lawrence Lenke, MD-20</td>
</tr>
<tr>
<td>11:30</td>
<td>Case Discussion</td>
</tr>
<tr>
<td>11:50 am</td>
<td>Q &amp; A</td>
</tr>
<tr>
<td>12:10 pm</td>
<td>Course Adjourns</td>
</tr>
</tbody>
</table>
Cervical Spondylotic Myelopathy: Anterior, Posterior, or Both

Dan Riew, MD
Professor, Orthopedic Surgery, Columbia University
Professor of Orthopedic Surgery in Neurological Surgery Departments,
Columbia University and Weill Cornell Medical College

Disclosures:

Royalties: Biomet, Nuvasive, Happe

Stocks: Osprey, Expanding Orthopedics, Spinal Kinetics, Amedica, Vertiflex,
Benvenue, Paradigm Spine, PSD, Spineology, Axiomed

Deputy/Associate Editor: Global Spine J, Spine, Neurosurgery, Neurospine
Orthopedics Today, Clinics in Orthopaedics,
Spine Surgery Today

Board: NASS
Anterior vs Posterior
Surgical Approaches to Treat CSM:
Outcomes of the Prospective Multicenter AOSpine North America CSM Study in 264 Patients
Fehlings, Barry, Kopjar, Yoon, Arnold, Massicotte, Vaccaro, Brodker, Shaffrey, Smith, Woodard, Banco, Chapman, Janssen, Bono, Sasso, Dekutoski, Gokaslan:

“It turns out that there is no difference in the outcomes between anterior vs posterior.”

- Overall similar outcomes and rates of complications
- Trade off dysphagia/dysphonia vs wound-related complications with posterior surgery

A Comparative Study Of Surgical Approaches For Cervical Compressive Myelopathy.

- Anterior vs laminoplasty
- ≥ 3 levels
- 136 pts Ave: 5.6 yrs
- No differences
Corpectomy vs Laminoplasty for Multi-Level Cervical Myelopathy:
An Independent Matched-Cohort Analysis:
_Edwards, Heller, Murakami; Spine, 27:1168-75, 2002._

• Axial pain same
• Analgesics tended to be greater for ACC
• Motion decreased 57% vs 38%
• 1 ACDF for HNP in laminoplasty group
• ACC: progression of myelopathy, nonunion, persistent dysphagia, persistent dysphonia, and subjacent motion segment ankylosis

---

Effect of Ventral vs Dorsal Spinal Surgery on Patient-Reported Physical Functioning in Patients With Cervical Spondylotic Myelopathy
A Randomized Clinical Trial

Zoher Ghogawala, MD; Norma Terrin, PhD; Melissa R. Dunbar, MPH; Janis L. Breeze, MPH; Karen M. Freund, MD, MPH; Adam S. Kanter, MD; Praveen V. Murimani, MD, MBA; Erica F. Bisson, MD, MPH; Fred G. Barker II, MD; J. Sanford Schwartz, MD; James S. Harrop, MD; Sudu N. Magge, MD; Robert F. Heary, MD; Michael G. Fehlings, MD, PhD; Todd J. Albert, MD; Paul M. Arnold, MD; X. Daniel Biew, MD; Michael P. Steinmetz, MD; Marjorie C. Wang, MD, MPH; Robert G. Whitmore, MD; John G. Heller, MD; Edward C. Benzel, MD

• PRMC
• 15 Centers
• 4/1/2014-3/30/2018 F/U 4/15/2020
• Randomized to A(63) or P (100)
• ACDF or Corpectomy vs Lami-fusion vs laminoplasty
• Surgeon’s discretion
• One-year SF-36 PCS mean improvement similar between A vs P
• Similar outcomes for neurologic recovery
Surgical Approaches

Anterior
• Arthroplasty
• ACDF
• Corpectomy

Posterior
• Laminectomy
• Laminoplasty
• Laminectomy & Fusion
• Laminoplasty & Fusion

Cervical Disc Arthroplasty Compared with Arthrodesis for the Treatment of Myelopathy
Riew, Buchowski, Sass, Zdeblick, Metcal, Anderson
JBJS-Am 2008;90:2354-2364

• Post-hoc, PRCM
• 2 yr
• No difference
• No worsening

Retrovertebral  Retrodiscal
Comparison of Cervical Disc Arthroplasty with ACDF for the Treatment of CSM


- Retrospective
- 37 Arthroplasty
- 39 ACDF
- 2 Yrs
- No difference

Arthroplasty for CSM: Similar Results to Patients with Only Radiculopathy at 3 Years’ Follow-up


- Retrospective, all arthroplasty
- 72 myelopathy
- 53 radiculopathy
- >24 mos
- Myelopathy improved
- No difference
Long-Term Outcomes of Arthroplasty for Cervical Myelopathy vs Radiculopathy, & Arthroplasty vs Arthrodesis for Cervical Myelopathy
Gornet, Riew, Lanman, Burkus, Hodges, McConnell, Dryer, Copay, Schranck:
*Neurosurgery, Volume 64, Issue CN_suppl_1, 1 September 2017, Pages 247*

- Post-hoc, PRCM
- 397 pts
- 84 mos
- 287 radiculopathy
- 110 myelopathy
- No difference

Results Suggest Arthroplasty Effective for CSM:

- Retrodisc Compression
- No Retrovertebral dz
- No OPLL
- No Kyphosis
- No facet arthrosis
- No inflammatory dz

Retrovertebral  Retrodiscal
Arthroplasty Technique

- More difficult than ACDF
- Precise technique
ACDF & ACCF

- Dysphagia
- Pseudarthrosis
- Loss of motion
- Adjacent level breakdown
- Immobilization in collar
- Activity restriction

Anterior Only

- Low pseudo risk
- Non-osteoporotic
- Increased risk from long A/P operation
- Difficult posterior wounds
Two Level

Sagittal Alignment

3-Levels:
Corpectomy-Discectomy

Corpectomy-Corpectomy
Myelopathy, Congenital Stenosis, C2-3 Autofused, C3-4 Partial Fusion, T1-3 Autofused 9/10 Neck Pain on Extension Facet Arthrosis C3-T1

Six Level Disease
Vertebral Artery
Abnormal Artery

Abnormal Anatomy

Discectomy
Instead of Corpectomy

• Oga, Spine 1994
Check MRI Preoperatively

Airway Compromise
Retropharyngeal Steroids

- Started in 2005
- Used with BMP (Off label) & A/P cases

Effect of Retropharyngeal Steroid on Prevertebral Soft Tissue Swelling Following ACDF: A Prospective, Randomized Study

- 50 patients 1-2 level ACDF
- 25 Steroids; 25 none
- Soft Tissue Swelling lower at 2,4,14 Days
- VAS for dysphagia better up to 2 weeks
Delayed Esophageal Perforation After ACF & Retropharyngeal Steroid Use: a Report of Two Cases


- 2 cases of delayed esophageal perforation
- Retropharyngeal steroids

2 Mos P-op

- Strep Viridans
- Repaired
- Re-repaired 2 wks later
- 4 Yr. F/U
Drain

- Prefer penrose drain
- ABD pad
- Transparent adhesive
- Soaked < 2 hours

Cuff Leak Test

Pass

Fail
Surgical Approaches

Anterior
• Arthroplasty
• ACDF
• Corpectomy

Posterior
• Laminectomy
• Laminaplasty
• Laminectomy & Fusion
• Laminaplasty & Fusion

Laminectomy: Ideal Candidate

• Spondylotic
• DISH
• Lordotic
• No Dural Tear
Kyphosis Can Occur Even In Good Hands

Avoid Laminectomy

- >3 levels
- C2
- C7
- Kyphosis
- C2-7 SVA >35
- T1 Slope > 30
Nucal Ligament

Semispinalis Cervicis

Origin: TP of T1-5  Insertion: C2-5
Skip Laminectomy


Pre-op  Post-op
Laminaplasty

Advantages

- Laminaplasty patients do well
- Decreased operative times, hospital stays
- Pseudarthrosis issues
- Manage expectations for neck pain
- Re-operations minimized
Advantages Over Anterior

- Immobilization
- Pseudo
- Dysphagia / Dysphonia
- Graft Extrusion

Complications

- Loss of extension
- Axial neck pain
- C5 palsy
- Bleeding
- Closure of laminaplasty
- Inadequate decompression
Laminaplasty Contraindications

- Intolerable neck pain
- Kyphosis
- Instability

Contraindications:
Neck Pain

- Mid-line axial neck pain
- Not TRAPEZIAL pain
- Tolerable vs intolerable
Neck pain following cervical laminoplasty: does preservation of the C2 muscle attachments and/or C7 matter?

- Yes
- C3 laminectomy instead of laminoplasty
- Avoid C7 if possible

Axial Symptoms After Cervical Laminoplasty With C3 Laminectomy Compared With Conventional C3–C7 Laminoplasty
A Modified Laminoplasty Preserving the Semispinalis Cervicis Inserted into Axis

Kazunari Takeuchi, MD,* Toru Yokoyama, MD,* Shuichi Akurakawa, MD,* Akira Saito, MD,* Takuya Umesawa, MD,* Tetsuya Iwasaki, MD,* Taito Itabashi, MD,* Akihiro Oda, MD,* Junji Ito, MD,* Kazumasa Ueyama, MD,* and Satoshi Tani, MD*
C3 Laminectomy, Undercut C7

Neck Pain Following Laminoplasty
Mesfin, Song, Chuntarapas, Piyaskulkaew, Kim, Xu, Hershman, Fogelson, Kennedy, Riew.

<table>
<thead>
<tr>
<th></th>
<th>Pre-op</th>
<th>6 Wk Post-op</th>
<th>p</th>
<th>1 Yr Post-op</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDI Total Score</td>
<td>12.5</td>
<td>10.1</td>
<td>.109</td>
<td>8.5</td>
<td>&lt;.002</td>
</tr>
<tr>
<td>NDI Pain Sub-score</td>
<td>1.29</td>
<td>0.87</td>
<td>&lt;.028</td>
<td>0.71</td>
<td>&lt;.007</td>
</tr>
</tbody>
</table>
103 pts with CSM
Sagittal alignment did not influence outcomes

Focal kyphosis > 13°
Neutral or mild kyphosis fine
Contraindications:

Kyphosis

K-line, Posterior drift
Muscle Destroying Dissection

Cervical Laminoplasty- A Critical Review
Ratlif and Cooper, J Neurosurg 2003

- Persistent axial pain
- Restriction of neck motions
- Postoperative malalignment

Courtesy T. Shiraishi
Post-op Muscle Atrophy

Meticulous Midline Dissection
Midline has no vessels and no muscles

Minimal blood loss
It’s Important to Preserve
The Cervical Interspinous Ligament: T or F

There is no cervical interspinous ligament
Interspinalis Muscle

Preserve Deep Extensor Musculature

1. Semispinalis cervicis
2. Multifidus
3. Long & short rotators
4. Interspinalis

Courtesy T. Shiraishi
Loss of Extension

Extend Neck & Remove Any Bone That Blocks Extension

• Irrigate bone dust
• Avoids auto-fusion
1cc syringe
Epidural depomedral 40mg
SQ depomedral 40 mg

Post-op

- No Collar
- Epidural Steroids, Vancomycin powder
- D/C home POD #1
- Immediate ROM exercises, ambulation
- Toradol during hospital stay
Hemostatic Techniques Reduce Hospital Stay Following Multilevel Posterior Cervical Spinal Surgery

Cho, Yi, Park, Hu, Zebala, Pahys, Kang, Lee, Riew

- Wound closed in multiple layers
- Drain output measured in 8-hour shifts
- Drain discontinued when ≤30 mL and patient discharged

Gel Foam in Thrombin

DON’T USE post-laminectomy
Methods to Decrease Post-Operative Infections Following Posterior Cervical Spine Surgery

Pahys, Pahys, Cho, Kang, Zebala, Hawasli, Sweet, Lee, Riew

1,001 consecutive posterior cervical operations
- Foraminotomy, laminectomy, laminaplasty, fusion, instrumentation, and/or osteotomies

MATERIALS & METHODS

- Alcohol and Drain Group (AD): n=323
  - Pre-prep the skin and surrounding plastic drapes with alcohol foam
  - Suprafascial drain placed in addition to subfascial drain in obese patients
  - 2004-2008
Vancomycin Powder

- Vancomycin powder .5-1gm
- Sprinkle before closure
- 0% infections for > 2 years
- Epidural Depomedral
  1cc of 40mg/cc

MATERIALS & METHODS

- Vancomycin-added Group (VAD): n=195
  - Similar protocol to Group AD
  - 500mg of vancomycin powder added to wound prior to closure
  - 2008-2010
Laminaplasty & Fusion
Vancomycin
Gelfoam + Thrombin

Never after laminectomy: expands to compress cord

Compress with Hands
Closure: Bone to Bone

Meticulous, Multilayer Closure w/ Small Bites
Large Bites Necrose Muscles
Overlap Suture to Prevent Dead Space

Dehisced Muscles Can’t Extend Neck
“Instability?”

Degenerative Spondylolisthesis Does Not Influence Surgical Results Of Laminoplasty In Elderly Cervical Spondylotic Myelopathy Patients.  

- > 2.5mm listhesis
- 1.0-2.5 mm excluded
- Flexion/extension ROM & clinical results at 3 yrs
- No significant difference

Laminectomy & Fusion

• Multi-level stenosis AND
• Neck pain, Kyphosis, Instability
Dynamic MRI Reveals Soft-Tissue Compression Causing Progressive Myelopathy in Postlaminectomy Patients
A Report of Three Cases
Stamm, McClellan, Knierim, Suter, Riew: *JBJS Case Connector* Vol 3:1 2/27/2013

Selective Fusion
C6-7 Foraminal Stenosis; Myeloradiculopathy
Laminectomy & Fusion

Little Room For Bone

Laminaplasty & Fusion
Laminaplasty & Fusion

C5, C8, T1 Palsy
Posterior Fusion

Advantage of Spinous Process Wires / Cables

- Long lever arm
- Temporary
- Better alignment

BUT Beware of foraminal stenosis causing neuro deficit

Extension Causes Root Compression
Posterior Positioning

- Hyperextension
- Taping

Posterior Fusion

- Tight foramen
- Pre-op lordosis position test
- Foraminotomy if numbness, pain, weakness
Foraminotomy May Not Help

Disc height loss = Short foraminal height

Avoid Sickle-Shaped Decompression: Maximize Flexion
Circumferential

- High pseudo risk
- Osteoporotic
- Deformity
- Increased Risk of Graft Extrusion
- Tumor
- Infection
- Unstable Trauma
- Save Fusion levels
- CP, Parkinson’s, movement disorder
- Multiply operated patient
- Early fusion desirable
Anterior 1\textsuperscript{st} Distracts

50 Y.O. RA, Myelopathy, Kyphosis
Backup Multilevel Corpectomy

Circumferential Fusion for Stenosis

Post-laminectomy Corpectomy
S/P XRT
Dropped Head
Neck pain
Myelo-Radiculopathy

Remove plate, C2-3, 5-6-7-T1-T2 ACDF (5-level)
Anterior: 2 hrs 25 min EBL: 25cc  Posterior: 3hrs 20 min EBL: 100cc

65 yo F: PJK, Osteoporotic
ACDF C4-7
PCF C4-7
70° Correction

Multiply Operated

3 Previous Operations
Long Corpectomies:

Graft Extrusion: 0-10%

2-Level Corpectomy

Courtesy, Sandy Emery
Backup Multilevel Corpectomy

Infection

Rigid Immobilization
- Allograft
- Cages
- Instrumentation
Osteo-ligamentous Injury

Is patient going to be compliant?
• Deformity corrected before rod
• Overbend rod for further correction
Adjacent Level Junction Kyphosis

43 y.o. s/p T2- L2 Fusion

Save Fusion Levels

T1 Corpectomy C7-T2 Fusion
26M 2ppd smoker from Kuwait
Numbness b/l ulnar distribution, L Hoffmann’s, hyperreflexia, bilateral clonus, +Romberg, tandem gait
Decision Making: Alignment

- Lordotic
- Neutral
- Mild kyphosis
- Severe kyphosis
Risk Factor Analysis for Adjacent Segment Pathology Requiring Surgery in 1358 Anterior, Posterior, Fusion and Non-fusion Cervical Spine Operations: Survivorship Analysis of 1358 patients

Decision Making: Pseudo Risk

- Smokers, Diabetics, Rheumatoids, etc
- Laminaplasty over fusion
Decision Making: Elderly

- +/- Minimize surgery
- Dysphagia w/ anterior
- Osteoporosis
- Pseudarthrosis
- Laminoplasty

Decision Making: Neck Pain

- Midline
- Unilateral – radicular
- Can they tolerate it
- Would they prefer to lose motion
Decision Making: Singers

Decision Making: Ossified Dura

Laminaplasty is Easier
Decision Making: Osteoporosis

- Laminaplasty
- Circumferential

Summary

- Numerous options
- Overlap of indications
- Surgeon choice
Thank You
Disclosure

I have no relevant financial relationships with any companies related to the content of this course.
Craniocervical junction:
1. Complex Embryology
2. Fulcrum of the pediatric cervical spine

<table>
<thead>
<tr>
<th></th>
<th>rotation</th>
<th>flex/ext</th>
<th>lateral bending</th>
</tr>
</thead>
<tbody>
<tr>
<td>O-C1</td>
<td>0-4</td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>C1-2</td>
<td>32-47</td>
<td>10</td>
<td>-</td>
</tr>
</tbody>
</table>

Kinematics
Classification of Pediatric Craniocervical Abnormalities

Acquired:
1. Trauma
2. Neoplastic

Genetic / Metabolic:
1. Skeletal Dysplasias
2. Osteogenesis imperfecta: basilar impression

Congenital Deformities
1. Occipital bone: basilar invagination
2. Atlas: aplasia, occipital assimilation
3. Chiari
Indications for Treatment:

Neurological Compression
- signs and symptoms
- imaging

Instability
- MRI
- Plain film criteria
- Anterior pathology

Neurological Compression:

**Signs and Symptoms**
- head tilt, stiff neck
- scoliosis
- myelopathy
- ataxia
- nystagmus
- sleep apnea
- hoarseness, dysphagia
- chronic cough
- neck pain
- suboccipital headache
- dizziness, syncope
- bowel bladder dysfunction

**Imaging (MRI)**
- Compression
- Cord signal change
- Syrinx
Clinical Instability at the Craniocervical Junction

Plain films remain a major practical consideration to determine instability: trauma

Atlantodental interval (ADI)
upper limit in flexion:

- 3-4mm
- 5mm (Punjabi and White)
- 6mm (Cadaver studies <10yo)

>10mm:
Alar and tectorial membrane secondarily damaged with O-C1 instability as well
Clinical Instability at the Craniovertebral Junction

Dens Basion Interval (DBI):

10-12.5 mm
- variable ossification of proatlas from 2-6yrs

Range of motion in flex/ext:
<1mm in adults (Wiesel)
<2 mm (Punjabi and White)
Clinical Instability at the Craniovertebral Junction

Basion-axial Interval (BAI):

0-12mm (Harris)
- does not extend posterior to the posterior axial line
- no flex/ext data

Clinical Instability at the Craniovertebral Junction

O-C1 Joint Interval:

5mm (Kauffman)
3mm (CT data; Pang)
Clinical Instability at the Craniovertebral Junction

½ Powers ratio <1  Lee X line
Distribution of MRI Abnormalities

- O-C2
- C2-3
- C3-4
- C4-5
- C5-6
- C6-7

Legend:
- Purple: Spinal Cord Lesion
- Yellow: Fracture
- Dark Purple: Extra-axial hemorrhage
- Green: Muscular Injury
- Light Blue: Ligamentous Injury
Tectorial Membrane Injury
Along the Spectrum of O-C2 Injury

- Isolated muscular abnormality
- Ligamentous abnormality:
  - Apical ligament
  - Unilateral joint disruption
  - **Tectorial membrane**
    - bilateral joint disruption
    - SCI
    - complete AO dislocation

Involvement of the Tectorial Membrane (TM) is a critical threshold for unstable ligamentous injury of the Craniocervical region

- All SCI occurred with TM injury
- All TM injuries also had AO joint disruptions
- All pts required fusion had TM injury
- Those treated without fusions had progressive MRI changes
- Abnormal O-C2 measurements were found only with TM injury
Clinical Instability at the Craniovertebral Junction
C1-2 Laminectomy
O-C6 Fusion
-Reduction, lum, postop

Treatment: Halo

SED 9yo, 14 kg, 78 cm (3yo) with myelopathy

Criteria for O-C2 instability in children

- >2.5 identified TM injury on MRI with 100% specificity
- Ossified
- Eliminates film distance variable
- Easily identifiable

C1-2: C2-3 Ratio
Skeletal Dysplasia:
Morquio’s, Spondyloepiphyseal Dysplasia

- O-C2 instability: ligamentous laxity
- hypoplastic C1, dens.
- Foramen magnum, C1 stenosis.
- Non-ossification

Treatment: reduction and fusion; decompression (posterior)
Congenital Occipital Disorders
Basilar Impression (tip of dens to Twining’s Line >30mm)
Osteogenesis Imperfecta

Sawin & Menezes: 25 pts
- 40% reducible with traction
- Irreducible compression treated by ventral decompression and posterior fusion
- No problems with fusion
- It's the progressive bone infolding: 80% basilar impression progressed
- Goal of treatment is palliative

Occipital segmental disorder: anterior atlas assimilation
5yo with basilar invagination (5mm above Chamberlain)
syrinx
Congenital Segmentation Failure:
Assimilation of the Posterior Atlas

- Isolated or in conjunction with Klippel-Feil, Chiari I.
- Excessive load on C1-2 motion segment or abnormal development of transverse ligament
10 yo isolated atlas assimilation, reducible AAD, OC1-C2 instability
Surgical Techniques
C2 translaminar screws
Chiari malformation
Unique Consideration of Clinical Instability at the Craniocervical Junction

**Anterior Pathology with Chiari:** basilar invagination, platybasia

Instability which is initiated or compounded by posterior decompression

2.5 Months Post-op: new acute nasal regurgitation, weak nasal voice, weak gag

Pre-Op 2.5 Months Post-Op
“Basilar Invagination” with Chiari:

- Will worsen after posterior decompression
- Anterior decompression along with posterior decompression and fusion.
  
  Boogard’s Angle > 130 (J Greenlee et al); pB-C2 > 9mm (Grabb et al)

11 yo Chiari, anterior pathology with downward nystagmus, ataxia
BONY relationships and ligamentous integrity:

Progressive instability can create imperceptible changes in compression may alter the CSF dynamics enough to produce a perceptible new syrinx: time to treat

Selected basilar invagination and Anterior pathology with Chiari I and/or syrinx represents craniocervical instability

-should be treated with posterior open reduction and fusion.
Down Syndrome:

- Recommend Fusion: Symptomatic ADI>6-8mm A-O motion > 10mm MRI Cord Signal Change dens abnormality

- Graft resorption...

Down Syndrome 4 month; Craniocervical dislocation
7 months (1st procedure C1 laminectomy, fusion 4mo)

13 months (Repeat fusion 7 months rib graft, 2.0mm plate and screw fixation)
• **Bone Morphogenetic Protein (BMP)** is a generic name for certain proteins extracted from bone matrix.

• BMPs are *osteoinductive* proteins.

• Osteoinductive: the ability to *induce/initiate* osteogenesis (bone formation).
s/p BMP: published as off label use in pediatric fusion

- Could be considered first line usage in Down patients

3 months

6 months

Unstable Os:
Spine surgeons:
Cardiac Gated sequence to detect thin mobile membranes
Craniocervical Stability
- O-c1-c2: 1 unit
- Bony relationship
- Relationship to neurological structure
- Impact on CSF dynamics
The Role of Reduction in Dysplastic Spondylolisthesis:

*Pediatric and Adult Considerations*

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

Disclosures

- Research/Institutional Support:
  - NIH, AO Spine, OREF, AOA

- Honoraria:
  - Medtronic, Stryker, Globus, Innovasis, Integrity, Camber

- Ownership/Stock/Options:
  - GreenSun Medical

- Royalties:
  - Medtronic, Stryker
Overview

• Impact of High Grade Olisthesis on Health Status

• The goals of surgery for dysplastic olisthesis are restoration of lordosis at L5-S1, preservation of neural function and solid arthrodesis

• Surgical Techniques
  • Posterior
  • Anterior and Posterior

• The Consequences of Poor Reduction of lumbosacral kyphosis
Dysplastic Olisthesis

Classification*

I) Dysplastic
II) Isthmic
   a) Lytic-fatigue fracture
   b) Elongated, intact pars
   c) Acute Fracture
III) Degenerative
IV) Traumatic
V) Pathologic
   OI, Albers-Schoenberg disease, arthrogryposis, tumor

*Wiltse LL, Newman PH, MacNab I: CORR 157, 1975
### Classification of Marchetti and Bartolozzi

<table>
<thead>
<tr>
<th>Developmental</th>
<th>High Dysplastic</th>
<th>With Lysis</th>
<th>With Elongation</th>
<th>Low Dysplastic</th>
<th>With Lysis</th>
<th>With elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquired</td>
<td>Traumatic</td>
<td>Acute Fracture</td>
<td>Stress Fracture</td>
<td>Post-surgery</td>
<td>Direct surgery</td>
<td>Indirect surgery</td>
</tr>
<tr>
<td></td>
<td>Pathologic</td>
<td>Local Pathology</td>
<td>Systematic Pathology</td>
<td>Degenerative</td>
<td>Primary</td>
<td>Secondary</td>
</tr>
<tr>
<td></td>
<td>Degenerative</td>
<td>Primary</td>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Spondylolisthesis – SDSG Classification

![Spondylolisthesis Classification](image)

*New Classification of Lumbar Spinal Slippage*

<table>
<thead>
<tr>
<th>Type</th>
<th>Lumbar Slippage</th>
<th>Sacropelvic Balance</th>
<th>Spinovalvar Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low (≤5%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Normal (≥10%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>High (&gt;10%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Balanced Low</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Unbalanced Low</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Unbalanced High</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*The spine is considered balanced if a patient has low or high-grade spondylolisthesis with a balanced spine.*

*Mac-Thiong et al. Spine 2012*
Sagittal alignment and quality of life

- In high-grade spondylolisthesis, an increasing positive sagittal alignment was related to a poorer SRS-22 total score.

- Severity of symptoms increases in a linear fashion with progressive positive sagittal imbalance.

Global sagittal alignment and health-related quality of life in lumbosacral spondylolisthesis

Adil Harrout · Hubert Labelle · Julie Joncas · Jean-Marc Mac-Thiong


- In high-grade spondylolisthesis, an increasing positive sagittal alignment was related to a poorer SRS-22 total score.
Vertebral Body Tethering: Successes and Failures

Amer F. Samdani, MD
Chief of Surgery
Shriners Hospitals for Children
Philadelphia, PA

Disclosures: Amer F. Samdani, MD

- Consultant: DePuy Synthes Spine, Ethicon, Globus Medical, Medical Device Business Systems, Mirus, NuVasive, Orthofix, Stryker, Zimmer Biomet
- Royalties: NuVasive, Zimmer Biomet (I receive royalties on the The Tether from ZB)
- Setting Scoliosis Straight Foundation: Board and Executive Committee
- Pediatric Spine Study Group: Executive Committee
Where are we today?

- Patient D.P.
  - 14-year-old boy with severe scoliosis
  - Gets short of breath from walking one block

Emerging Areas:
Prognostication, 3D, *Growth Modulation*
Scoliosis Surgery: Where We Came From…

- Preoperative traction / casting
- Operate through a cast
- 6 months in the hospital
- Limited correction
- High reoperation rate
- Anterior, posterior hooks, screws

PSF Remains Gold Standard

- Reliable
- Safe
  - IONM
  - Implants
Tethering Provides an Option

Utilizing Remaining Growth

- Bowlegs, knock knees
  - Growth modulation techniques
- Orthodontics
  - Bracing
- Plagiocephaly
  - Helmets
Tethering Not the First Attempt at Growth Modulation

Fusion After Failed Stapling

No spontaneous fusion
Option: Brace vs. Staples

- Braun et al (2005) and Peter Newton
- Better results in goat model using bone tether than staples

Braun et al. The efficacy and integrity of shape memory alloy staples and bone anchors with ligament tethers in the fusionless treatment of experimental scoliosis. JBJS 87A(9):2038-51, 2005
Who? Current Indications

- Skeletal immaturity
  - 11-13 years girl, 12-15 years boy
  - Risser 0-3
  - Sanders stage ≤ 5
  - *More on this later*

- Deformity
  - Thoracic/lumbar curves
    - 35° (40°) to 65°
  - Flexible below 30°
  - *Failed bracing*

11 y/o Girl

Pre-op  6 months  1 year  4 years
Data to Support??

- Long-term studies
- Tether breakages
- Reoperations
- Motion
  - How does it fare with respect to gold standard of fusion?
- Importance of thoracic motion preservation?

Literature

- Animal studies: Abundant
- Human: Rapidly increasing
  - Newton PO et al: Anterior spinal growth modulation in skeletally immature patients with idiopathic scoliosis. JBJS-A 2020 Feb 19 [ePub]
  - Miyanji F: Results of VBT at 2 years. IMAST 2017
  - Alanay A: Results of VBT at Skeletal Maturity. SRS 2019
  - Hoernschemeyer D: VBT at minimum 2 years of follow-up. POSNA 2019
SRS 2021 Program

- Half day course, lunchtime symposium
- 12 accepted papers
  - Most still early experience (2 years), one 10 year report
  - Motion
  - Pulmonary function
  - Comparison to fusion

Prospective Follow-Up of Anterior Vertebral Body Tethering for Idiopathic Scoliosis: Interim Results from an FDA IDE Study

Amer F. Samdani, MD; Joshua M. Pahys, MD; Robert J. Ames, MD; Harsh Grewal, MD; Glenn J. Pelletier, MD; Steven W. Hwang, MD; Randal R. Betz, MD

Accepted JBJS
Methods

- FDA-approved IDE study
- Identified all skeletally immature patients with Lenke 1A and B curves between 30-65° operated between 2011-2015
- Clinical and radiographic parameters collected until age 18
- X-rays read independently by outside vendor
- FDA worked with us to expedite

Patient Demographics

<table>
<thead>
<tr>
<th>Demographic / Patient Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>N = 57</td>
</tr>
<tr>
<td>Female</td>
<td>49 (86%)</td>
</tr>
<tr>
<td>Male</td>
<td>8 (14%)</td>
</tr>
<tr>
<td>Age at surgery (years)</td>
<td>12.4 (1.3)</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>10.1, 15.0</td>
</tr>
<tr>
<td>Min, max</td>
<td></td>
</tr>
<tr>
<td>Menarchal (49 girls)</td>
<td>7 (14.9%)</td>
</tr>
<tr>
<td>Yes</td>
<td>40 (85.1%)</td>
</tr>
<tr>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Risser score</td>
<td>0 (0-3)</td>
</tr>
<tr>
<td>Sanders score</td>
<td>3 (&lt;6)</td>
</tr>
</tbody>
</table>
# Follow-Up

<table>
<thead>
<tr>
<th>Operative / Inpatient Variable</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Follow-up (months)</td>
<td>55.2 ± 12.5</td>
</tr>
<tr>
<td>Age at last visit (years)</td>
<td>17.1 ± 1.4</td>
</tr>
<tr>
<td>Risser score</td>
<td>4.2 ± 0.9</td>
</tr>
<tr>
<td>Sanders stage</td>
<td>7.5 ± 0.9</td>
</tr>
</tbody>
</table>

## Operative Data

<table>
<thead>
<tr>
<th>Operative / Inpatient Variable</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>N = 57</td>
</tr>
<tr>
<td>Levels tethered</td>
<td>7.5 ± 0.6</td>
</tr>
<tr>
<td>Duration of surgery (minutes)</td>
<td>223.2 (79.4)</td>
</tr>
<tr>
<td>Blood loss (mL)</td>
<td>105.7 (85.9)</td>
</tr>
<tr>
<td>Days in ICU</td>
<td>1.5 (0.7)</td>
</tr>
<tr>
<td>Length of stay (days)</td>
<td>4.8 (1.4)</td>
</tr>
</tbody>
</table>
# Radiographic: Coronal Plane

<table>
<thead>
<tr>
<th>Visit</th>
<th>Main thoracic curve (°)</th>
<th>Proximal thoracic (°)</th>
<th>Lumbar curve (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-op</td>
<td>40.4 ± 6.8</td>
<td>25.0 ± 5.7</td>
<td>23.7 ± 6.1</td>
</tr>
<tr>
<td>First erect</td>
<td>19.3 ± 8.4</td>
<td>20.1 ± 5.5</td>
<td>15.2 ± 6.1</td>
</tr>
<tr>
<td>24 months</td>
<td>13.8 ± 8.9</td>
<td>15.3 ± 6.9</td>
<td>11.4 ± 7.7</td>
</tr>
<tr>
<td>Most recent</td>
<td>18.7 ± 13.4</td>
<td>17.9 ± 6.4</td>
<td>15.7 ± 8.4</td>
</tr>
</tbody>
</table>

80% of patients < 30° at most recent follow-up

# Sagittal Plane

<table>
<thead>
<tr>
<th>Visit</th>
<th>T5-12 kyphosis (°)</th>
<th>Lumbar lordosis (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-op</td>
<td>15.5 ± 10.0</td>
<td>51.9 ± 11.4</td>
</tr>
<tr>
<td>First erect</td>
<td>17.0 ± 10.1</td>
<td>50.9 ± 10.6</td>
</tr>
<tr>
<td>24 months</td>
<td>17.8 ± 11.9</td>
<td>53.0 ± 10.3</td>
</tr>
<tr>
<td>Most recent</td>
<td>19.6 ± 12.7</td>
<td>54.4 ± 11.8</td>
</tr>
</tbody>
</table>

Humanitarian Device Approval August 2019
Successes and Failures Following Spinal Growth Tethering for Scoliosis: A Retrospective Look 2 to 4 Years Later
Newton et al: SRS 2016, JBJS 2018

- 17 consecutive patients
  - Risser 0, mean age 11 years, mean thoracic scoliosis 52º
  - 2-4 years of follow-up
- 9/17 were considered to have a successful outcome (reduction of thoracic Cobb to < 30º)
- Good initial correction but inconsistent midterm outcomes
  - Revision surgery required for approx. 50% of patients

Anterior Vertebral Body Tethering for Adolescent Scoliosis With Growth Remaining: A Retrospective Review of 2 to 5-Year Postoperative Results
Hoernshemeyer et al, JBJS-A 102:1169, 2020

- 29 skeletally immature patients
  - Mean Sanders score 4.1, Risser 1.8
  - 2-5 years of follow-up (27 reached skeletal maturity)
- Analyzed:
  - Lenke 1A (11)
  - Lenke 1B (8)
  - Long thoracic (4)
  - Lenke 5 (4)
  - Double tethers (2)
Results of Anterior Vertebral Body Tethering at Skeletal Maturity

**SRS 2020**

- 83 patients
- Both thoracic and lumbar curves tethered
- Skeletal maturity
  - Girls Risser ≥ 4
  - Boys Risser ≥ 5
- Major Cobb angle
  - Pre-op 48°
  - FE 22°
  - 2 year 15°
  - Latest (avg. of 5 years) 21°

74% < 30° at skeletal maturity
Results of Anterior Vertebral Body Tethering at Skeletal Maturity

*SRS 2020*

- Reoperations
  - 18/83 (21.7%)
  - 11 (13.2%) for overcorrection (wait until triradiates closing)
  - 4 (4.8%) for adding on
  - 3 fusion (3.6%)

Reoperations

- Overcorrection
  - Younger patient, usually triradiates open
  - Technique-related
- Undercorrection
  - Curve too stiff and/or not enough growth
- Adding on
  - Usually if tethered short of CSVL
Too Much Growth: Overcorrection

Immediate post-op

1 year

2 years

2 years after tether cut

Pre-op

Likely a “Sweet Spot” for Growth Remaining

Triradiate open

Risser 1
Sanders 4

Risser 5
Sanders 8
“Ideal First Patient”

- Radiographic
  - Thoracic moderate, flexible curve
  - Not too much rotation
  - Beware C curve pattern
  - Preferably T5 - T11 or 12
  - Lumbar - perhaps bigger impact, but I find technically more demanding
- Triradiates closed, Sanders 4
- Family understands risks, benefits, and potential for reoperation (tether release)

Correcting the Spine

- Patient selection paramount
  - Bend x-rays but clinical exam provides enough information
  - Bends < 35°
- Factors to consider
  - Remaining growth
  - Magnitude and flexibility of curve
  - Balancing both
- Compress across apical levels and leave distal end loose
Intra-op vs. Erect

Patient Z.H.
Mature Patients: Tethering?

- Disc releases
  - Pain, fusion?
- Two surgery minimum
  - 6 months apart replace the tether
  - Anterior revision surgery can be challenging
- When tethers break
  - Double tethers (may only delay the inevitable)
  - Stiffness
- Why not just fuse the patient?
Option 1:
Right T5-T11 tether (double)
Left T11-L4 tether (double)
Apical disc releases
Change tether at 6 months
Wait and pray

Option 2:
Selective thoracic fusion

Patient M.D.

Radiographic: Coronal Plane
(88 Patients > 5 Year Follow-up)

<table>
<thead>
<tr>
<th></th>
<th>Main Thoracic Curve (°)</th>
<th>Lumbar Curve (°)</th>
<th>Proximal Thoracic Curve (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-op</td>
<td>48.4 ± 10.7</td>
<td>28.9 ± 10.8</td>
<td>22.6 ± 9.8</td>
</tr>
<tr>
<td>First Erect</td>
<td>22.0 ± 10.4</td>
<td>16.5 ± 7.3</td>
<td>16.2 ± 7.5</td>
</tr>
<tr>
<td>2 Year</td>
<td>14.9 ± 10.7</td>
<td>12.7 ± 9.0</td>
<td>13.1 ± 8.2</td>
</tr>
<tr>
<td>Most Recent</td>
<td>21.5 ± 12.6</td>
<td>16.4 ± 9</td>
<td>13.8 ± 7.4</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>
Tether Breakages

- Incidence
  - Newton et al JBJS 2018
    - 47% (8/17) patients, one required reoperation
  - Hoernschemeyer et al JBJS 2020
    - 48% (14/29), 2 (14%) required fusion

Not All Broken Tethers Are Failures

P Newton et al, SRS 2016
Patient A.G.

- 12-year-old girl
  - Premenarche
  - Risser 0
  - Sanders 4
  - Major curve
    - T6-L2: 58°

Surgery

- Underwent T6-L2 tether
- Discussion
  - Access to L2
  - How much correction?
Follow-up

First Standing PA/Lat 3 months 6 months

Growth Spurt

6 months 12 months 5 years
Breakages: Tips

- Can be difficult to pick up, typically > 5° change in disc angulation
- I have seen mostly distal thoracic, lumbar and apex
- Screw alignment, BMI?
- Vast majority asymptomatic but important to counsel families that an increase in angle can occur

Outside of FDA Indications

- 10-year-old girl, myelomeningocele
  - L5 level
  - Ambulatory
  - VPS
  - Premenarche
  - Triradiates closing
  - Progressive scoliosis
  - T6-L2: 78°
Options

- Growing system
  - Rib to pelvis as definitive?
- Fusion
  - Approach?
  - Levels?
- Other?
- Complications
  - Infection
  - Shunt
- Tether
  - Reasonable trunk control
  - Growth remaining
WHY Consider Anterior Growth Modulation?

- Adjacent level degeneration later
- Maybe better sagittal compensation
- Hypothetically, mobile spine better than fused spine

Flexibility

Motion Analysis Lab
**Forward Flexion**

- Posterior fusion
- Vertebral body tethering

**Extension**

- Posterior fusion
- Vertebral body tethering
Degrees of Lumbar Motion Loss at 6 Months and 2 Years for PSF and VBT During Forward Flexion

Our Approach

- 11 year old
  - Premenarche
  - Triradiates closing
  - Initially presented with right thoracic 55° curve and left lumbar 45°
- 4 months later progressed to thoracic 72°, lumbar 68°
Offer (Strongly) Selective Thoracic Fusion Whenever Feasible
Thoracolumbar Curve: J.S.

- 12-year-old boy
- Triradiates just closing
- Sanders 3
- Cobb
  - T8-L3: 48°
  - T2-T6: 32°

Avoid Lumbar Fusion Whenever Possible
Patient L.G.

- 10-year-old boy
- Progressive curve despite bracing

Pre-op 1st Erect 12 Months
Patient L.G.

Height at time of surgery = 153 cm
Most recent height = 175 cm
Growth = 22 cm (8.7 inches)

When to cut tether

1 year 2 year 3 year 4 year 5 year
Vertebral body tethering offers patients a viable option to fusion.

- Improved mobility comes at the cost of less predictability and higher reoperation rate.
- FDA approval for idiopathic patients but other diagnoses may benefit more.
- Shared decision making allows us to push the indications, but it is imperative that we look at our data often.
Opiate Use, Abuse, and Dependency Prevention in Spine Surgery

Sina Pourtaheri, MD
Gulf Coast Orthopedics

Sina Pourtaheri, MD: Nothing to Disclose
OPIOID CRISIS

> 70,200 OVERDOSE DEATHS IN US (47,600 OF THOSE OVERDOSE DEATHS INVOLVED OPIOIDS)

> 130 PEOPLE DIED EVERY DAY FROM OPIOID-RELATED DRUG OVERDOSES

$12 BILLION (US BUDGET 2018) FOR PREVENTION AND TREATMENT OF OPIOID ADDICTION

SPINAL AILMENTS IS PART OF THE OPIOID CRISIS

NECK AND BACK PAIN ARE THE ONE OF THE MOST COMMON MEDICAL CONDITIONS ASSOCIATED WITH OPIOID ADDICTION

SPINE SURGERY ON PATIENTS WITH PREOPERATIVE CHRONIC PAIN SYNDROME AND OPIOID ADDICTION IS UNLIKELY TO RESULT IN THE PATIENT BECOMING OPIOID-FREE.
WHAT TO DO?

OPTIMIZE THE LIMBIC SYSTEM AND PAIN PATHWAYS

FIXING THE RADIOGRAPHIC PROBLEM ALONE DOESN’T ALLEVIATE THE PAIN SIGNIFICANTLY

INTERACTION OF LIMBIC SYSTEM AND PAIN PATHWAY
“PREDICTORS OF LONG-TERM OPIOID USE FOLLOWING LUMBAR FUSION SURGERY”

#1. DURATION OF OPIOID USE PRIOR TO SURGERY
1–22 DAYS [OR=2.27]
≥ 250DAYS [OR=219.95]

#2. UNTREATED MENTAL HEALTH ISSUES
Surgical factors play less of a role
(REVISION FUSION, SURGICAL APPROACH)

[8337 PATIENTS; SPINE 2017]

MENTAL HEALTH IN SPINE SURGERY

SPINE 1992
86 PATIENTS (MICRODISCECTOMIES)

NO CHILDHOOD TRAUMAS – 95% EXCELLENT IMPROVEMENT
1-2 CHILDHOOD TRAUMAS – 73% IMPROVEMENT
3+ CHILDHOOD TRAUMAS – 15% IMPROVEMENT
LITERATURE ON PREOPERATIVE OPTIMIZATION OF LIMBIC SYSTEM/PAIN PATHWAYS PRIOR TO SURGERY (PREHAB)

1) TRANSITION FROM OPIOIDS TO NON-OPIOID MEDICATIONS PRIOR TO SURGERY
2) PSYCHOTHERAPY (BEHAVIOR MEDICINE) FOR THE CHRONIC PAIN SYNDROME AND MENTAL HEALTH ISSUES
3) PHYSICAL THERAPY (ACT PROGRAM) TO ALLOW MOTION WITH AN ACCEPTABLE LEVEL OF PAIN W/ AND W/O WEIGHT LOSS
4) SMOKING CESSATION (BEHAVIORAL MEDICINE)
5) ETOH CESSATION (BEHAVIORAL MEDICINE)

HYPOTHESIS

INITIATION OF PREHAB [AN INTERDISCIPLINARY PROTOCOL OF THE AFOREMENTIONED, EVIDENCE-BASED RECOMMENDATIONS] COULD DECREASE OPIOID CONSUMPTION AND PAIN IN PATIENTS GOING FOR SPINE SURGERY WITH PREOPERATIVE OPIOID ADDICTION AND CHRONIC PAIN SYNDROME.
STUDY DESIGN

COLLABORATION BETWEEN SPINE SURGERY, PSYCHIATRY, PSYCHOLOGY, PAIN MANAGEMENT, PHARMACY, PRIMARY CARE, PHYSICAL THERAPY, AND NUTRITIONIST WAS INITIATED.

INCLUSION CRITERIA WERE PATIENTS UNDERGOING ELECTIVE SPINE SURGERY IN THE VA SYSTEM WHO HAD PREOPERATIVE CHRONIC PAIN SYNDROME AND OPIOID ADDICTION.

COMPARSED OUTCOMES AFTER SURGERY WITH AND WITHOUT PREHAB (89 VERSUS 85 PATIENTS)

DEMOGRAPHICS AND SURGICAL PROCEDURES WERE SIMILAR BETWEEN THE COHORTS

<table>
<thead>
<tr>
<th>Demographics in Each Cohort</th>
<th>No Prehab</th>
<th>Prehab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>59.6</td>
<td>57.3</td>
</tr>
<tr>
<td>Male</td>
<td>89.4%</td>
<td>91.0%</td>
</tr>
<tr>
<td>Female</td>
<td>10.6%</td>
<td>9.0%</td>
</tr>
</tbody>
</table>

Case Breakdown in Each Cohort

<table>
<thead>
<tr>
<th>Procedure</th>
<th>No Prehab</th>
<th>Prehab</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACDF</td>
<td>14 (16.5%)</td>
<td>12 (13.5%)</td>
</tr>
<tr>
<td>PCF</td>
<td>5 (5.9%)</td>
<td>7 (7.9%)</td>
</tr>
<tr>
<td>A/PCF</td>
<td>1 (1.2%)</td>
<td>2 (2.3%)</td>
</tr>
<tr>
<td>ALIF</td>
<td>10 (11.8%)</td>
<td>9 (10.1%)</td>
</tr>
<tr>
<td>PLF</td>
<td>9 (10.6%)</td>
<td>7 (7.9%)</td>
</tr>
<tr>
<td>A/PLF</td>
<td>7 (8.3%)</td>
<td>9 (10.1%)</td>
</tr>
<tr>
<td>Microdiscectomy</td>
<td>18 (21.2%)</td>
<td>22 (24.7%)</td>
</tr>
<tr>
<td>Laminectomy</td>
<td>21 (24.7%)</td>
<td>21 (23.6%)</td>
</tr>
<tr>
<td>Revision</td>
<td>12 (14.1%)</td>
<td>15 (16.9%)</td>
</tr>
<tr>
<td>Number of Levels</td>
<td>172 (2.0)</td>
<td>191 (2.1)</td>
</tr>
</tbody>
</table>

*PCF = Posterior Cervical Fusion
A/PCF = Anterior and Posterior Cervical Fusion
A/PLF = Anterior and Posterior Lumbar Fusion
Number of Levels = Number of Levels Treated
OPIOID-FREE WITH LESS PAIN [PREHAB]

OPIOID-FREE 6 MONTHS AFTER SURGERY
72% (PREHAB) VS 8% (NO PREHAB) [P<0.0001]

<table>
<thead>
<tr>
<th>Improvement in Visual Analog Scores in Each Cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>No Prehab</td>
</tr>
<tr>
<td>Prehab</td>
</tr>
</tbody>
</table>

BETTER QUALITY OF LIFE WITH HEALTHIER RELATIONSHIP WITH PAIN

QALYs One Year After Surgery in Each Cohort

<table>
<thead>
<tr>
<th></th>
<th>No Prehab</th>
<th>Prehab</th>
</tr>
</thead>
<tbody>
<tr>
<td>QALYs</td>
<td>0.59</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Mean Values for CPAQ and PCS One Year After Surgery

<table>
<thead>
<tr>
<th></th>
<th>CPAQ activity</th>
<th>CPAQ willing</th>
<th>CPAQtotal</th>
<th>PCStotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Protocol</td>
<td>35.4</td>
<td>23.4</td>
<td>58.8</td>
<td>25.0</td>
</tr>
<tr>
<td>Post-Protocol</td>
<td>51.3</td>
<td>37.8</td>
<td>89.1</td>
<td>12.6</td>
</tr>
</tbody>
</table>
PATIENT SATISFACTION

86% [NO REHAB COHORT] WERE SATISFIED WITH THEIR RESULTS AND WOULD HAVE SURGERY AGAIN

98% [REHAB COHORT]

CONCLUSIONS

COLLABORATION IS KEY TO SOLVE A DIFFICULT PROBLEM

OVER THE LAST 2 DECADES THE MAJORITY OF THE SURGERY SPINE LITERATURE HAS FOCUSED ON RADIOGRAPHIC PARAMETERS

WE NEED MORE RESEARCH AND GUIDELINES IN ADDRESSING THE LIMBIC SYSTEM BEFORE AND AFTER SURGERY
CONCLUSIONS

IN PATIENTS WITH OPIOID ADDICTION, SOME VERSION OF REHAB IS BENEFICIAL [PREHAB VERSUS POSTOPERATIVE REHAB]

THE OPIOID CRISIS ALLOWS OPPORTUNITIES FOR IMPROVEMENT IN SPINE CARE

HIGH PATIENT SATISFACTION IN SURGERY ALONE DESPITE THE PATIENTS REMAIN ADDICTED TO OPIOIDS WITH RESIDUAL HIGH LEVELS OF PAIN (VAS SCORES)

NECK AND LOWER BACK PAIN TREATMENT COSTS

~$100 BILLION/YEAR WITH 6.5% INCREASE PER YEAR

#1 DIABETES
#2 HEART DISEASE
#3 SPINE CARE
Dr. Walter Freeman, left, and Dr. James W. Watts study an X ray before a psychosurgical operation. Psychosurgery is cutting into the brain to form new patterns and rid a patient of delusions, obsessions, nervous tensions and the like.
POSTERIOR VCR FOR SEVERE PEDIATRIC DEFORMITY: TIPS, TRICKS, ALTERNATIVES

LAWRENCE G. LENKE, MD
PROFESSOR AND CHIEF OF SPINAL SURGERY
CHIEF OF SPINAL DEFORMITY SURGERY
COLUMBIA UNIVERSITY MEDICAL CENTER

SURGEON-IN-CHIEF
THE DANIEL AND JANE OCH SPINE HOSPITAL
NYP/ALLEN

UCSF CME PEDIATRIC AND ADULT SPINE SURGERY COURSE
AUGUST 4-7, 2021

DISCLOSURES
LAST 36 MONTHS

• Royalties: Medtronic (substantial), Quality Medical Publishing (minor).
• Consulting: Medtronic, EOS Technologies, Abyrx, Acuity Surgical (monies directed to a charitable foundation)
• Grants: EOS Technologies, SSS Foundation, ISSG Foundation, AOSpine,
• Board: OREF, GSO, SSS
• Philanthropic /Society Research Funding: Fox Family (Prospective Pediatric Spinal Deformity study); AOSpine & SRS (Scoli-Risk 1 study).
• Travel/Accommodations: AMCICO, AOSpine, BroadWater, COA, DePuy Synthes Spine, Medtronic, SOSORT, SRS, SSF, The Spinal Research Foundation.
SEVERE PEDIATRIC DEFORMITY

VCR: VERTEBRAL COLUMN RESECTION

• Removal of an Apical Vertebra(e) Thereby Separating the Spine into 2 Sections That can be Shortened and then Rejoined to Correct Even the Most Severe Spinal Deformities

N= 325 Cases/20 Years
“SPINAL DISARTICULATION” INHERENT TO THE VCR IS A DOUBLE-EDGE SWORD THAT ALLOWS TREMENDOUS CORRECTION BUT HAS TREMENDOUS RISK

VCR IS HIGH REWARD...WITH HIGH RISK!!!

2000-PATIENT FROM MOSCOW RUSSIA TREATED WITH A VCR

Nappie JJ, Lancaster LG. Severe idiopathic scoliosis with respiratory insufficiency treated with preoperative traction and staged anteroposterior spinal fusion with a 2-level apical vertebrectomy. Spine J 2009;9(7):e9
POST. VCR: 5 LESSONS LEARNED OVER 20 YEARS AND > 350 CASES

1. Procedure of Last Resort - PCO's work well for most Deformities
2. VCR is Best for Severe/Rigid/Angular Deformities - DAR term
3. Use of SCM is Essential with Appropriate Responses
4. Correction Mechanics can be Complicated and Requires Secure Fixation with Screws/Hooks Periapically
5. The Radiographic and Clinical Corrections and Pt. Satisfaction are Outstanding with Results Durable up to a min. 5 Yrs. Postop!
6. However, It is a Technically Demanding Procedure that Can have Significant Morbidity and even Mortality

Complications after 147 Consecutive Vertebral Column Resections for Severe Pediatric Spinal Deformity. A Multicenter Analysis

Lawrence G. Lenke, MD; Peter O. Newton, MD; Daniel J. Sucato, MD; Harry L. Shuffelbarger, MD; John B. Emans, MD; Paul D. Sponseller, MD; Suken A. Shah, MD; Brenda A. Sides, MA; Kathy M. Blanke, RN

Spine 2013;38(2):119-32
Acknowledge: John and Marcella Fox Research Fund
COMPLICATIONS: Intraoperative

- 68/147 (39%) had an intraop complication
  - n=39/147 (27%) → lost SCM data/actual SC or NR deficit documented
  - 22/147 (15%) → EBL > 100% Blood Volume
- No Paraplegics, one pt with major Motor Neuro function loss with only partial recovery

PSF C6-L4/2 Level PVCR

Clinical and Radiographic Outcomes after Posterior Vertebral Column Resection with 5 Year Follow Up: Analysis of 55 Pts

Michael P. Kelly, MD
Lawrence G. Lenke MD
Daniel G. Kang MD
Jamal McClendon, Jr. MD
Lionel N. Metz MD
Brenda A. Sides
Kathy M. Blanke

JBJS 2018
SRS OUTCOME SCORES (n=55)

“ABSOLUTE” VCR INDICATIONS FOR SEVERE PEDIATRIC DEFORMITY

- PREVIOUS 3-COLUMN FUSIONS (CONG. OR IATROGENIC) WITH RESIDUAL DEFORMITY
- HIGH DEGREE OF ANGULARITY ESP. WITH MYELOPATHY
- MOST “SEVERE DEFORMITIES” ESP WITH “BAYONETTING” AND/OR “OMEGA” DEFORMITIES
- COMBINATION OF ABOVE
CONG. LORDOSCOLIOSIS WITH CIRCUMFERENTIAL FUSION T3-T10

PREOP FEV-1: 31% Predicted

PSF C7-L3/T7&T8 VCR/PCO’S T10-12

+50 DEG KYPHOSIS CORRECTION
SEVERE KYPHOSCOLIOSIS WITH NF/MYELOPATHY

S/P ASF AND PSF X 4

“ANGULARITY”

• DAR=Deformity Angular Ratio: Max Cobb Measurement Divided by # of Vertebral Segments Involved

DAR: 159/8=19.9

SPINE 2016
SCSCS: SPINAL CORD SHAPE CLASSIFICATION SYSTEM: PREDICTING NEUROMONITORING POSITIVE EVENTS

<table>
<thead>
<tr>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odds Ratio = 0.17</td>
<td>Odds Ratio = 0.66</td>
<td>Odds Ratio = 28</td>
</tr>
</tbody>
</table>

SIELATYCKI, LENKE ET AL SPINE DEFORMITY 2020

TYPE 3M (MYELOPATHY) SC CLASSIFICATION

NewYork-Presbyterian Daniel and Jane Och Spine Hospital
PSF C7-L3/3-LEVEL VCR

PRE & POST CLINICAL PHOTOS
POST. VCR FOR SEVERE PEDIATRIC DEFORMITY

• TIPS- PREOP
• TRICKS
• ALTERNATIVES

PREOPERATIVE HEALTH OPTIMIZATION

• Training
  • Pulmonary
  • Aerobic Exercise

• Nutrition
  • Enteral- Oral vs G-Tube
  • Hyperalimentation (Lenke, et al. Spine 1995)

• Stretching
  • Side-bending/traction
NEUROFIBROMATOSIS/S-P 4 PRIOR SURGERIES/AGE 17

HALO-GRAVITY TX.
GASTROSTOMY TUBE

NF- SEVERE UNTREATED KYPHOSCOLIOSIS
BENEFIT OF PREOP 3D MODEL.....ESSENTIAL!

T2-L2 = 2.5 CM

PRE TRACTION PFT’S

<table>
<thead>
<tr>
<th>Spirometry</th>
<th>Actual</th>
<th>Pred</th>
<th>%Pred</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV1 (L)</td>
<td>0.77</td>
<td>2.95</td>
<td>26</td>
</tr>
<tr>
<td>FEF 25-75% (L/sec)</td>
<td>0.31</td>
<td>2.80</td>
<td>11</td>
</tr>
<tr>
<td>FEF 50% (L/sec)</td>
<td>0.41</td>
<td>3.86</td>
<td>11</td>
</tr>
<tr>
<td>FVC (L)</td>
<td>1.13</td>
<td>6.98</td>
<td>36</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lung Volumes</th>
<th>Actual</th>
<th>Pred</th>
<th>%Pred</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLC (Pleth) (L)</td>
<td>3.20</td>
<td>5.35</td>
<td>60</td>
</tr>
<tr>
<td>SVC (L)</td>
<td>1.25</td>
<td>3.75</td>
<td>33</td>
</tr>
<tr>
<td>IC (L)</td>
<td>0.91</td>
<td>2.34</td>
<td>39</td>
</tr>
<tr>
<td>ERV (L)</td>
<td>0.34</td>
<td>1.41</td>
<td>24</td>
</tr>
<tr>
<td>RV (Pleth) (L)</td>
<td>1.94</td>
<td>1.93</td>
<td>101</td>
</tr>
<tr>
<td>RV/TLC (Pleth) (%)</td>
<td>61</td>
<td>36</td>
<td>169</td>
</tr>
<tr>
<td>TV (L)</td>
<td>2.29</td>
<td>3.01</td>
<td>76</td>
</tr>
</tbody>
</table>
HALO-GRAVITY TRACTION- INC 8.5 CM HEIGHT

HALO-GRAVITY TRACTION- IMPROVED VERTICALIZATION OF PROX THORACIC SPINE
**POST TRACTION PREOP PFT’S**

**Patient History**
Diagnosis: MM, KYPHOSIS, PREOP

**Medication**

<table>
<thead>
<tr>
<th>Tobacco Products: No</th>
<th>Dyspnea Rest: No</th>
<th>Dyspnea Exercise: Yes</th>
<th>Cough: No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>How Long (yrs):</td>
<td>Quit: No</td>
<td>Stopped(ys):</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spirometry</th>
<th>Pre</th>
<th>Ref</th>
<th>%Ref</th>
<th>Post</th>
<th>%Ref</th>
<th>%Chg</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC</td>
<td>1.53</td>
<td>2.87</td>
<td>24</td>
<td>1.60</td>
<td>56</td>
<td>5</td>
</tr>
<tr>
<td>FEV1</td>
<td>0.96</td>
<td>2.37</td>
<td>42</td>
<td>1.21</td>
<td>51</td>
<td>23</td>
</tr>
<tr>
<td>FEV1/FVC %</td>
<td>64</td>
<td>84</td>
<td></td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEV6</td>
<td>1.40</td>
<td>1.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEV1/FEV6 %</td>
<td>67</td>
<td>76</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEF25-75 L/sec</td>
<td>0.49</td>
<td>2.67</td>
<td>18</td>
<td>0.92</td>
<td>34</td>
<td>87</td>
</tr>
<tr>
<td>FEF75 L/sec</td>
<td>0.18</td>
<td>1.21</td>
<td>15</td>
<td>0.33</td>
<td>27</td>
<td>85</td>
</tr>
<tr>
<td>PEF</td>
<td>3.17</td>
<td>5.60</td>
<td>57</td>
<td>4.68</td>
<td>84</td>
<td>48</td>
</tr>
<tr>
<td>FET100% Sec</td>
<td>9.65</td>
<td>7.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PII</td>
<td>3.28</td>
<td>3.43</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PSF T1-L4/T7-9 VCR/NEURO IMPROVED**
POST. VCR FOR SEVERE PEDIATRIC DEFORMITY

• TIPS
• TRICKS- INTRAOP
• ALTERNATIVES
ANTIFIBRINOLYTIC AGENTS REDUCE BLOOD LOSS DURING PEDIATRIC VERTEBRAL COLUMN RESECTION PROCEDURES

- EBL was sig. greater in No AF group (n=64; avg 52% EBV) vs. those receiving TXA (n=22; avg 30% EBV, p<0.001) and Amicar (n=30; avg 32% EBV, p<0.05)

Newton, Boestrom, Emans, Shah, Shufflebarger, Sponseller, Sucato, Lenke

Spine 2012;9(8):432-46

Acknowledge: John and Marcella Fox Research Fund
TRANEXAMIC ACID (TXA)

- Potent Antifibrinolytic
- Inexpensive
- Several studies show a decrease in Intraop/early postop EBL
- **Low-dose*** (10 mg/Kg load +1 mg/Kg/hr maintenance – Adults)
- **High-dose**** (50 mg/Kg load + 5 mg/Kg/hr maintenance – Peds)
- **Super High-dose** (100 mg/Kg load + 10 mg/kg/hr maintenance)

*Zebala, Lenke et al. IMAST 2010
**Rahman, Lenke et al. SRS 2011

Myelopathic Patients Who Lack Spinal Cord Monitoring Data Have the Highest Risk of Spinal Cord Deficits Following Posterior VCR Surgery

Samuel K. Cho, MD; Lawrence G. Lenke, MD; Shelly M. Bolon, BS; Joshua M. Pahys, MD; Woojin Cho, MD, PhD; Matthew M. Kang, MD; Lukas P. Zebala, MD; Linda A. Koester, BS
Washington University School of Medicine
Barnes-Jewish Hospital
St. Louis Children’s Hospital
Shriners Hospital for Children - St. Louis Unit
St. Louis, Missouri, USA

45th Scoliosis Research Society Annual Meeting
Kyoto, Japan
September 2010
HIGHEST NEURO RISK......

• Angular Kyphosis
• Preop Myelopathy
• Prior ASF with Seg Vessels Ligated
• Upper-mid Thoracic Spine
• NO SCM POSSIBLE!

• Only 1 Pt. with Nml Preop SC Function has had a SCM Loss without Recovery and awoke with LE Paralysis- Normalized by 2 months.

CURVE CLASSIFICATION 4A+/L4
PSF T2-L4(0)/T10 VCR

PRE & POSTOP CLINICAL PHOTOS
JIS S/P 5 POST. SURGERIES/1 ANT. FUSION

CIRCUMFERENTIALLY FUSED KYPHOSCOLIOSIS

“CONSTRUC-CONSTRUCT” CORRECTION
REV PSF/2-LEVEL VCR T1-L4 PSF
COMPARISON OF STANDARD 2-ROD TO MULTIPLE-ROD CONSTRUCTS FOR FIXATION ACROSS 3-COLUMN (3-CO) SPINAL OSTEOTOMIES

• **132** Consecutive 3-CO by a single surgeon
• **66 pts** with Standard 2-Rod construct across 3-CO site vs **66 pts** with Multiple-Rods (3-5) across the 3-CO site
• Min 2 yr Postop: Rod Fx rate at 3-CO site:
  - 2-Rod Group: **13 pts** (19.7%) - 7 Revised
  - Multi-Rod Group: **2 pts** (3.0%), 0 Revised

(p< 0.002)

Hyun SJ, Lenke L et al SPINE 2014

3 RODS ACROSS VCR SITE/RIBS PLACED COVERING THE LAMINECTOMY DEFECT
OTHER TECHNICAL CORRECTION TRICKS

• OPTIMAL PS PURCHASE ESSENTIAL!
• GO SLOW! ALLOWS BONE-SCREW INTERFACE AND NEURAL ELEMENTS TIME TO ADJUST
• ALWAYS HAVE 2 TEMP RODS IN PLACE AS SOON AS POSSIBLE TO AVOID SUBLUXATION
• LOOSEN CONTRALATERAL SIDE AS A “TRACKING ROD” DURING IPSILATERAL CORRECTION
• MAINTAIN CORRECTION OBTAINED WITH TEMP RODS BY EITHER “HOOK-ROD” TEMP CONSTRUCT OR DUAL-HEADED SREWS
• CANTILEVER IN PERMANENT ROD FOR ADDITIONAL CORRECTION, ESP FOR KYPHOTIC/KYPHOSCOLIOTIC DEFORMITIES

REVISION PSF T1-L1 WITH T6,7,8 VCR

+135°
+55°
DUEL HEADED SCREWS USED FOR TEMP RODS/PERMANENT ROD INSERTIONS!

Does Planned Staging for Vertebral Column Resections Increase Perioperative Complications?

*Spine Deform* 2016;4(2):131-137

- Gum J*, Lenke LG, Bridwell KH, Zhao J‡, Bumpass DB*, Sugrue PA*, Karikari IO*, Carreon LY.

• NO! No difference in Complications between 1 stage and 2 stage VCR’s
SK- S/P PSF X 4

HX. OF PRIOR DWI/IMPLANTS D/C’D
REV PSF C3-SAC/L1 VCR: 13 HOURS
17 Y/O NOONAN SYNDROME; 4 PRIOR SPINE SURGERIES; HEART SURGERY
1ST STAGE: L1 VCR COMP ON LEFT/ KICKSTAND DISTRACTION ON RIGHT

INTRAOP

10/16/19  10/21/19  10/28/19  11/25/19
19 Y/O WITH MMC & S/P L2-L5 PSF AGE 9

TISSUE EXPANDERS!
UTILIZE PLASTIC SURGICAL EXPERTISE WHENEVER POSSIBLE!
METHODS TO AVOID VCR

- MULTILEVEL PCO’S
- PRELIM HGTx THEN MULTILEVEL PCO’S
- TEMP INTERNAL DISTRACTION/CONVEX COMPRESSION
- PERIAPICAL PCO’S AND APICAL FUSION MASS TRANSLATION

- ULTIMATELY, ACCEPTING LESS DEFORMITY CORRECTION TO OPTIMIZE PATIENT SAFETY!

SEVERE IDIOPATHIC DM SCOLIOSIS
PSF T2-L4/PCO’S T5-L3

POST-LAMI SEVERE SCOLIOSIS
3 WEEKS OF PREOP HGTx

PSF T1-L4, PERIAPICAL PCO’S
18 Y/O MALE: CONG KYPHOSCOLIOSIS: S/P VEPTR REMOVAL WITH SOLID FUSION T5-T12/POOR CARDIAC STATUS/PREVIOUS ON HOSPICE

EOS- CONG KYPHOSCOLIOSIS: S/P VEPTR REMOVAL WITH SOLID FUSION T5-T12/POOR CARDIAC STATUS/PREVIOUS ON HOSPICE
CONCLUSIONS: VCR FOR SEVERE PED DEFORMITY

• VCR: Severe, Fixed, Angular Deformities with/without Myelopathy
• Powerful Correction but Challenging for Patient and Surgeon
• Tips and Tricks are Now More Widely Known and Practiced to Ensure Better Safety
• Alternatives involving PCO’s can often Mitigate VCR Approach
THANK YOU!

LL2989@COLUMBIA.EDU
SPINAL-DEFORMITY-SURGEON.COM
Sagittal Plane Considerations in AIS

Stephen G. George, MD

Director of Spine Surgery
Nicklaus Children’s Hospital
Miami, FL

Disclosures

• Consultant- Stryker
AIS: 3-Dimensional Deformity

• Morphologic change in the building block

• Vertebral Body
  • Anterior column overgrowth causes lordotic vertebra
  • “Coupled Motion” produces deformity in all 3 planes
    • Posterior tethering
    • Lordosis
    • Rotation
    • Lateral translation

AIS: 3-Dimensional Deformity

Classic Results:
Thoracic Hypokyphosis
Chicken or the Egg?

Sagittal Plane Analysis of the Spine and Pelvis in Adolescent Idiopathic Scoliosis According to the Coronal Curve Type

- Curve type was not a/w sagittal pelvic morphology and balance
- Thoracic kyphosis is significantly influenced by curve type
- Lumbar lordosis is influenced by PI

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Thoracic Kyphosis</th>
<th>Lumbar lordosis</th>
<th>Pelvic incidence</th>
<th>Sacral Slope</th>
<th>Pelvic Tilt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>King 1 (n = 30)</td>
<td>20.4 ± 8.4°</td>
<td>41.9 ± 11.3°</td>
<td>57.0 ± 15.7°</td>
<td>48.1 ± 13.1°</td>
<td>8.9 ± 5.5°</td>
</tr>
<tr>
<td>King 2 (n = 36)</td>
<td>22.0 ± 11.6°</td>
<td>40.7 ± 9.4°</td>
<td>58.1 ± 12.6°</td>
<td>46.2 ± 5.4°</td>
<td>10.5 ± 5.6°</td>
</tr>
<tr>
<td>King 3 (n = 43)</td>
<td>20.3 ± 12.0°</td>
<td>46.8 ± 16.9°</td>
<td>56.3 ± 12.8°</td>
<td>47.8 ± 6.2°</td>
<td>8.4 ± 7.4°</td>
</tr>
<tr>
<td>Thoracic-lumbar (n = 21)</td>
<td>25.7 ± 11.0°</td>
<td>41.9 ± 11.7°</td>
<td>58.3 ± 12.4°</td>
<td>46.7 ± 8.6°</td>
<td>10.5 ± 5.7°</td>
</tr>
<tr>
<td>Lumbar (n = 21)</td>
<td>26.6 ± 10.9°</td>
<td>45.4 ± 10.8°</td>
<td>56.4 ± 14.3°</td>
<td>46.4 ± 10.3°</td>
<td>10.3 ± 5.1°</td>
</tr>
<tr>
<td>P value (ANOVA)</td>
<td>0.683*</td>
<td>0.335</td>
<td>0.008</td>
<td>0.875</td>
<td>0.752</td>
</tr>
</tbody>
</table>

Significant change (p < 0.05).

2013 Outstanding Paper Runner-up

Differences in early sagittal plane alignment between thoracic and lumbar adolescent idiopathic scoliosis

- Early thoracic scoliosis showed a significantly different sagittal plane from lumbar scoliosis.
- For thoracic scoliosis, a significantly longer posteriorly inclined segment, and steeper posterior inclination of C7–T8 was observed compared to Controls and lumbar scoliosis.

- Posterior inclination of a vertebra renders itself to more rotational instability.
Importance of 3D assessment for Sagittal Plane

- Kyphosis is overestimated in 2D radiographs by approximately 10 degrees.
- Kyphosis is underestimated in 2D radiographs by approximately 10 degrees.

Significant differences between 2D and 3D plane measurements of TK.

The difference between 2D and 3D plane measurements strongly correlates with the degree of apical rotation.
Thoraco-lumbar alignment in the sagittal plane

206 operative AIS from the Harms Study Group Database

- **Thoracic kyphosis (2D)**
  - Lenke 1AL (N=33): 32.5 ± 13.3 vs. 28.5 ± 17 (T(73)=1.106, p=.272)
  - Lenke 1AR (N=42): -1.4 ± 10.9 vs. -1 ± 11.9 (T(73)=-.155, p=.877)

- **Lumbar lordosis (2D)**
  - Lenke 1AL: -59.1 ± 10.5 vs. -55.3 ± 14.2 (T(73)=-1.298, p=.199)
  - Lenke 1AR: -0.8 ± 7.6 vs. -4.5 ± 6 (T(73)=-2.118, p=.038)

- **Pelvic incidence (deg)**
  - Lenke 1AL: 53 ± 9.5 vs. 52.8 ± 12.7 (T(73)=.105, p=.916)
  - Lenke 1AR: 3 ± 6.5 vs. 3 ± 7.5 (T(73)=1.325, p=.201)

- **Thoraco-lumbar kyphosis (3D)**
  - Lenke 1AL: -4.5 ± 8.5 vs. -8.75 ± 8.1 (T(68)=2.118, p=.038)
  - Lenke 1AR: -17.1 ± 7.7 vs. -12.1 ± 9.1 (T(69)=2.469, p=.016)

**Potential diagnostic and surgical implications**

- Patients with 1AR curves have a more lordotic TL alignment compared to TL curves in different AIS curve types.

- **Axial rotation (3D)**
  - Lenke 1AL: 3 ± 13 vs. 3 ± 13.3 (T(69)=1.325, p=.201)
  - Lenke 1AR: 3 ± 13 vs. 3 ± 13.3 (T(69)=1.325, p=.201)

**The differing features of the TL junction**

- Patients with type 1A curves: analysis using segmental 3D measurements

**Thoraco-lumbal alignment is crucial in level selection for type 1A curves.**

---

**Podium Presentation SRS 2019, Montreal**

- Patients with 1AR curves have a more lordotic TL alignment compared to 1AL curves as measured using segmental 3D analysis.

- The differing features of the TL junction likely effect the variance in the risk of distal adding-on for type 1A curves.
Type 1AR

Type 1AL

3D Imaging

2D Imaging
Importance of restoration of thoracic kyphosis

Sagittal balance and idiopathic scoliosis: does final sagittal alignment influence outcomes, degeneration rate or failure rate?

- Restoration of sagittal alignment may be more important than selection of LIV in AIS
- Improved kyphosis can lead to increase in lung volumes and improved pulmonary function
- Preservation of kyphosis essential to decrease the incidence of PJK
- Improved kyphosis is essential for restoration of lordosis

Goals of Surgical Correction

Pre-operative considerations:

1. Do no harm – Just because there’s a deformity, doesn’t mean we can’t make it worse or harm the patient!
2. Stop progression of deformity
3. Restore/preserve global balance, anatomic harmony, sustainable/durable construct/fusion, reduce likelihood of future complications
4. Preserve as many motion segments as possible
What can a surgeon do for correction?

Pre-operative considerations:

- Pay careful attention to sagittal plane (Not just the T1, T12 and L5 sagittal tilts)
- Look for kyphosis in the thoraco-lumbar junction
- Look for proximal thoracic hyperkyphosis
- Always measure the PI-LL
- If possible, assess the thoracic/TL sagittal alignment in 3D

Pedicle screws in AIS

- Strong anchor of all three columns of the vertebra
- Excellent potential for derotation
- Greater construct rigidity and minimal loss of correction over time

Hypokyphosing effects of Pedicle screws

Comparative Analysis of Pedicle Screw Versus Hybrid Instrumentation in Posterior Spinal Fusion of Adolescent Idiopathic Scoliosis
Yongjung J. Kim, MD, Lawrence G. Lenke, MD, Junghoon Kim, MD, Keith H. Bridwell, MD, Samuel K. Che, MD, Gene Cheh, MD, and Brian Sides, MA
Spine 2006

A Pedicle Screw Construct Gives an Enhanced Posterior Correction of Adolescent Idiopathic Scoliosis When Compared With Other Constructs
Myth or Reality
Vagner Vora, MS, Erin A. Price, MD, Alvin Crawford, MD, Kristin Babashok, MD, Shetha Beato, MD, Xiaoqian Liu, MD, Scott W. Pashman, MD, and Yongjung Kim, MD
Spine 2007

Operative Treatment of Adolescent Idiopathic Scoliosis With Posterior Pedicle Screw-Only Constructs
Minimum Three-Year Follow-up of One Hundred Fourteen Cases
Ronald A. Lehman, Jr, MD, Lawrence G. Lenke, MD, Kathryn A. Koehler, MD, Yongjung J. Kim, MD, Jacob M. Buchowski, MD, MS, Gene Cheh, MD, Craig A. Kuhns, MD, and Keith H. Bridwell, MD
Spine 2008

➢ All these studies suggest that pedicle screw constructs leads to decreased thoracic kyphosis post-operatively

Uniplanar Versus Fixed Pedicle Screws in the Correction of Thoracic Kyphosis in the Treatment of Adolescent Idiopathic Scoliosis (AIS)
Siddharth A. Badve, MD, Ryan C. Goodwin, MD, David Gard, MD, Thomas Kuvilla, MD, and William F. Lavelle, MD

| Pediatr Orthop • Volume 37, Number 8, December 2017 | Uniplanar Versus Fixed Pedicle Screws |

| TABLE 3: Comparison of Radiographic Parameters by Type of Anchor for Lenke 1 and Lenke 2 Patients |

<table>
<thead>
<tr>
<th></th>
<th>Fixed Screws</th>
<th>Uniplanar Screws</th>
<th>Comparison</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average no. levels fixed for each group</td>
<td>10.4</td>
<td>11.0</td>
<td>ANOVA</td>
<td>0.04</td>
</tr>
<tr>
<td>Average preoperative coronal Cobb (range) (deg.)</td>
<td>50 (25-72)</td>
<td>52.4 (34-80)</td>
<td>ANOVA</td>
<td>0.7</td>
</tr>
<tr>
<td>Average postoperative coronal Cobb (range) (deg.)</td>
<td>61 (13-135)</td>
<td>66 (40-102)</td>
<td>ANOVA</td>
<td>0.9</td>
</tr>
<tr>
<td>Average postoperative sagittal Cobb (T5-T12) (range) (deg.)</td>
<td>10.4 (1-54)</td>
<td>19.5 (0-45)</td>
<td>ANOVA</td>
<td>0.5</td>
</tr>
<tr>
<td>Average postoperative sagittal Cobb (T5-T12) (range) (deg.)</td>
<td>27.4 (0-126)</td>
<td>24.7 (20-82)</td>
<td>ANOVA</td>
<td>0.62</td>
</tr>
<tr>
<td>Average postoperative sagittal Cobb (T5-T12) (range) (deg.)</td>
<td>22.4 (14-127)</td>
<td>23.2 (12-37)</td>
<td>ANOVA</td>
<td>0.85</td>
</tr>
<tr>
<td>Average postoperative sagittal Cobb (T5-T12) (range) (deg.)</td>
<td>214.4 (40-59)</td>
<td>41 (24-59)</td>
<td>ANOVA</td>
<td>0.56</td>
</tr>
</tbody>
</table>

➢ Significant improvement in kyphosis with uniplanar screws, d/t ability to adapt to sagittal orientation
The most predictive factor identified was the surgeon performing the correction, likely reflecting a focus on 3D deformity correction, as well as a combination of methods used to restore kyphosis.

Spine Rotational Rigidity:

- Removal of the anterior 2/3 of disc leads to a 90% reduction of rotational stiffness
- Removal of posterior column support leads to a 30% reduction of rotational stiffness
- Removal of posterior osteotomies

Biomechanics of the Spine

Is it the screws or the surgeon?
Intra-operative considerations

Aggressive Posterior column releases/Ponte Osteotomies

TIP: Levels selection for Ponte osteotomies should also be based on the region of thoracic hypo-kyphosis. The levels selection for Ponte osteotomies should also include the adjacent levels that will be treated.

CoCr rods have a greater stiffness, better endurance limit and a good yield strength compared to 25% higher compared to CoCr rods. Maximum yield of CoCr is 55% higher compared to peak stress.

Choice of Rod (Material)

- CoCr has the highest stiffness, better endurance limit and a good yield strength.
- Titanium has high yield strength.
- Endurance limit of CoCr is 25% higher compared to SS, UHSS or Ti in response to repetitive bending.
- CoCr rods have a greater stiffness, better endurance limit and a good yield strength.

Properties - A review of the literature

Choice of rods in surgical treatment of adolescent idiopathic scoliosis. Their clinical implications and biomechanical characteristics.
Choice of Rod (Diameter)

- Stiffness of a rod ~ (Radius)

- Soft tissue coverage is often the limiting factor.

- Coronal curve correction
  - A 6.35mm rod leads to better kyphosis restoration compared to a 5.0mm rod but no change in
  - 4.75 mm ~ 2 x stiffer than 4.0 mm
  - 5.5 mm ~ 2 x stiffer than 4.75 mm
  - 6.35 mm ~ 2 x stiffer than 5.5 mm

- Maximum lordosis below L4

- Required lordosis between L1-L4

Based on Pr. V to obtain 40% of

TL junction is usually flat

Absolutely 2-dimensional plane contouring

Concave rod over bent (non-round rod)

Differential Rod Contouring

Over-bent concave rod

Under-bent convex rod
Concave Segment Lengthening (For Thoracic Hypokyphosis)

- Postero-medial translation is most effective when enough length of the spine is maintained by distraction of the concave segment.
- Must use caution not to overlengthen the distal two screws to achieve indirect length of the main concave segment.
- Best achieved using alternate compression and distraction between the distal two screws to achieve indirect length of the main concave segment.

Crowded Teeth Concept (For Thoracic Hypokyphosis)
**Concave Segment Lengthening**  
(For Thoracic Hypokyphosis)

**Crowded Teeth Concept**

![Diagram of concave segment lengthening](image1)

**Stable Arch**

Locking the construct proximally and distally  
Then slow reduction, rely on viscoelastic properties of the spine

![Diagram of stable arch](image2)
Convex Segment Shortening (Lumbar Scoliosis)

Three-dimensional radiographic outcomes following selective thoraco-lumbar fusion in Lenke types 5 and 6 Adolescent idiopathic scoliosis.

Subaraman Ramchandran, MD; Harry L. Shufflebarger, MD; Ali Monsour MD; Stephen G. George, MD

Simultaneous peri-apical segmental direct vertebral derotation and convex segment compression resulted in:
1) Improved derotation of apical vertebra
2) Improved correction of coronal TL curve
3) Improved spontaneous resolution of thoracic curve
4) Improved restoration of thoracic kyphosis
14yo Postmenarchal Female

12yo Postmenarchal Female
Disclosures

• Nuvasive – consultant, grant funding
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

The impact of obesity on perioperative complications in patients undergoing anterior lumbar interbody fusion

Michael M. Safaee, MD, Alexander Tenorio, BA, Joseph A. Osorio, MD, PhD,
Winward Choy, MD, Dominic Amara, BA, Lillian Lai, BS, Annette M. Molinaro, PhD,
Yafan Zhang, MS, Serina S. Hu, MD, Bobby Tay, MD, Shane Burch, MD, Sigurd H. Berven, MD,
Vedat Deviren, MD, Sanjay S. Dhall, MD, Dean Chou, MD, Praveen V. Murmaneni, MD,
Charles M. Eichler, MD, Christopher P. Ames, MD, and Aaron J. Clark, MD, PhD

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 >= 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
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 GCM was associated with significant radiographic and HRQOL improvement despite high complication rates. MCID improvement was highest for SRS-22r Appearance/Self-Image. A residual GCM ≥ 3 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.

Bao H¹, Yan P¹, Qu Y¹, Liu Z², Zhu F².

- Less reliably corrected (Type C)
- Preop coronal malalignment due to a trunk shift ipsilateral to apex of degen thoracolumbar scoliosis
- 60% persistent malalignment
The role of the fractional lumbosacral curve in persistent coronal malalignment following adult thoracolumbar deformity surgery: a radiographic analysis

Alekos A. Theologis1 · Thamrong Lertudompophonwanit2 · Lawrence G. Lenke3 · Keith H. Bridwell3 · Munish C. Gupta3

• Retrospective review (2008-2014)
• Posterior-only spinal instrumented fusions (including sacrum; ≥5 levels)
• Thoracolumbar scoliosis
• Primary Operations

• 124 patients (divided based on Bao classification)
• Type A: 87
• Type B: 19
• Type C: 18
Table 2. Radiographic results

<table>
<thead>
<tr>
<th></th>
<th>Preoperative</th>
<th>After LIF</th>
<th>p-value</th>
<th>After PSF</th>
<th>p-value</th>
<th>Last follow-up</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean±SD</td>
<td>Mean±SD</td>
<td></td>
<td>Mean±SD</td>
<td></td>
<td>Mean±SD</td>
<td></td>
</tr>
<tr>
<td>Lumbar lordosis (°)</td>
<td>36.4±13.7</td>
<td>48.9±12.8</td>
<td>&lt;0.001</td>
<td>53.9±12.6</td>
<td>&lt;0.001</td>
<td>56.1±11.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pelvic tilt (°)</td>
<td>23.0±9.7</td>
<td>15.6±9.2</td>
<td>&lt;0.001</td>
<td>20.6±9.1</td>
<td>0.12</td>
<td>21.2±8.2</td>
<td>0.256</td>
</tr>
<tr>
<td>PI–LL mismatch (°)</td>
<td>22.2±15.9</td>
<td>8.1±13.9</td>
<td>&lt;0.001</td>
<td>5.9±12.7</td>
<td>&lt;0.001</td>
<td>4.0±13.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Thoracic coronal Cobb (°)</td>
<td>20.8±13.0</td>
<td>16.0±14.7</td>
<td>&lt;0.001</td>
<td>9.2±10.2</td>
<td>&lt;0.001</td>
<td>9.3±9.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lumbar coronal Cobb (°)</td>
<td>38.6±19.5</td>
<td>24.1±16.6</td>
<td>&lt;0.001</td>
<td>12.6±8.2</td>
<td>&lt;0.001</td>
<td>13.5±9.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Coronal imbalance (mm)</td>
<td>19.2±27.3</td>
<td>26.6±32.8</td>
<td>0.222</td>
<td>15.3±18.1</td>
<td>0.384</td>
<td>15.7±22.8</td>
<td>0.428</td>
</tr>
<tr>
<td>Sagittal vertical axis (mm)</td>
<td>61.7±49.5</td>
<td>58.2±63.6</td>
<td>0.88</td>
<td>42.2±44.3</td>
<td>0.039</td>
<td>42.0±49.5</td>
<td>0.058</td>
</tr>
</tbody>
</table>

p-values compared to preoperative values. *Three months after posterior spinal fusion. 1Mean duration until last radiographic follow-up was 17.4 months.

Comparative analysis of 3 surgical strategies for adult spinal deformity with mild to moderate sagittal imbalance

Jansee-K Bae, MD; Alexander A. Theologis, MD; Russell Strom, MD; Bobby Tay, MD; Shane Burch, MD; Sigurd Berven, MD; Praveen V. Mummameni, MD; Dean Chou, MD; Christopher P. Ames, MD; and Vedat Diviren, MD

1Department of Neurological Surgery, Woosinl Eupin Hospital, Seoul, South Korea; and Departments of Orthopedic Surgery and Neurological Surgery, University of California, San Francisco, California

Table 3. Summary of complications

<table>
<thead>
<tr>
<th>Complication</th>
<th>All Patients</th>
<th>LIF+PSF</th>
<th>ALIF+PSF</th>
<th>PSF-Only</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PK (%)</td>
<td>35.7</td>
<td>32.4</td>
<td>41.8</td>
<td>38.9</td>
<td>0.045</td>
</tr>
<tr>
<td>PK mechanism (%)</td>
<td>16.5</td>
<td>15.5</td>
<td>16.2</td>
<td>15.6</td>
<td>0.554</td>
</tr>
<tr>
<td>Scoliosis (%)</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>0.999</td>
</tr>
<tr>
<td>Upright</td>
<td>25.8</td>
<td>24.1</td>
<td>27.7</td>
<td>23.9</td>
<td>0.849</td>
</tr>
<tr>
<td>Spondylolisthesis (%)</td>
<td>4.5</td>
<td>0.0</td>
<td>5.5</td>
<td>0.9</td>
<td>0.142</td>
</tr>
<tr>
<td>Revision due to PK (%)</td>
<td>12.7</td>
<td>8.6</td>
<td>13.2</td>
<td>11.3</td>
<td>0.571</td>
</tr>
<tr>
<td>Revision due to non-PK (%)</td>
<td>25.3</td>
<td>24.1</td>
<td>27.7</td>
<td>24.7</td>
<td>0.674</td>
</tr>
<tr>
<td>Pseudarthrosis (%)</td>
<td>10.0</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>0.342</td>
</tr>
<tr>
<td>Hardware prominence (%)</td>
<td>8.1</td>
<td>6.9</td>
<td>5.5</td>
<td>12.5</td>
<td>0.392</td>
</tr>
<tr>
<td>Complications (%)</td>
<td>4.5</td>
<td>3.4</td>
<td>4.4</td>
<td>5.5</td>
<td>0.544</td>
</tr>
<tr>
<td>Infection (%)</td>
<td>16.6</td>
<td>15.5</td>
<td>20.9</td>
<td>18.1</td>
<td>0.709</td>
</tr>
<tr>
<td>Neuroradiology (%)</td>
<td>6.2</td>
<td>10.3</td>
<td>7.3</td>
<td>7.0</td>
<td>0.775</td>
</tr>
<tr>
<td>Cardiopulmonary (%)</td>
<td>14.5</td>
<td>17.2</td>
<td>17.6</td>
<td>8.3</td>
<td>0.197</td>
</tr>
<tr>
<td>Vascular (%)</td>
<td>1.4</td>
<td>3.4</td>
<td>1.1</td>
<td>8.0</td>
<td>0.235</td>
</tr>
<tr>
<td>Gastrointestinal (%)</td>
<td>10.0</td>
<td>6.9</td>
<td>9.6</td>
<td>12.5</td>
<td>0.571</td>
</tr>
<tr>
<td>Renal (%)</td>
<td>4.5</td>
<td>8.6</td>
<td>3.3</td>
<td>2.8</td>
<td>0.205</td>
</tr>
<tr>
<td>Aneurysm (%)</td>
<td>5.77</td>
<td>5.52</td>
<td>6.6</td>
<td>5.0</td>
<td>0.125</td>
</tr>
<tr>
<td>Operative (%)</td>
<td>4.1</td>
<td>0.0</td>
<td>5.5</td>
<td>1.6</td>
<td>0.370</td>
</tr>
<tr>
<td>Total complications (mean ± SD)</td>
<td>15 ± 11</td>
<td>16 ± 11</td>
<td>15 ± 12</td>
<td>13 ± 9</td>
<td>0.082</td>
</tr>
</tbody>
</table>

Note: *= indicates statistical significance.

Table 5. MCID achievement

<table>
<thead>
<tr>
<th>HRQoL Measure</th>
<th>All Patients (%)</th>
<th>LIF+PSF (%)</th>
<th>ALIF+PSF (%)</th>
<th>PSF-Only (%)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS</td>
<td>60.7</td>
<td>62.5</td>
<td>62.0</td>
<td>44.8</td>
<td>0.092</td>
</tr>
<tr>
<td>Leg pain</td>
<td>47.0</td>
<td>46.4</td>
<td>44.8</td>
<td>44.0</td>
<td>0.916</td>
</tr>
<tr>
<td>ODI</td>
<td>45.8</td>
<td>44.2</td>
<td>43.4</td>
<td>36.4</td>
<td>0.217</td>
</tr>
<tr>
<td>SRS-22</td>
<td>63.4</td>
<td>60.4</td>
<td>62.0</td>
<td>42.3</td>
<td>0.002</td>
</tr>
<tr>
<td>Function</td>
<td>63.4</td>
<td>60.4</td>
<td>57.7</td>
<td>57.7</td>
<td>0.395</td>
</tr>
<tr>
<td>Self-image</td>
<td>51.5</td>
<td>52.0</td>
<td>52.1</td>
<td>38.5</td>
<td>0.205</td>
</tr>
<tr>
<td>Mental health</td>
<td>42.6</td>
<td>41.7</td>
<td>42.3</td>
<td>42.3</td>
<td>0.973</td>
</tr>
<tr>
<td>SF-36 PCS</td>
<td>56.5</td>
<td>54.2</td>
<td>54.2</td>
<td>42.4</td>
<td>0.539</td>
</tr>
</tbody>
</table>

Bracket type indicates statistical significance.
Utility of multilevel lateral interbody fusion of the thoracolumbar coronal curve apex in adult deformity surgery with open posterior instrumentation and L5–S1 interbody fusion: a case-matched evaluation of 32 patients

Alexander A. Theologis, MD; Gregory M. Mundis Jr, MD; Stacie Nguyen, MPH; David O. Okonkwo, MD, PhD; Praveen V. Mummamani, MD; Justin S. Smith, MD, PhD; Christopher I. Shaffrey, MD; Richard Feaster, MD; Shay Beaz, MD; Frank Schwebi, MD; Bassel G. Dibbo, MD; Douglas Burton, MD; Robert Hart, MD; Vedat Deviren, MD; and Christopher Ames, MD, for the International Spine Study Group

<table>
<thead>
<tr>
<th>Variable</th>
<th>All</th>
<th>L5–S1 Group</th>
<th>L5–Only Group</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of pts</td>
<td>32</td>
<td>18</td>
<td>14</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age</td>
<td>63.0 ± 10.3</td>
<td>64.0 ± 10.0</td>
<td>62.1 ± 10.9</td>
<td>0.62</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>0.33</td>
</tr>
<tr>
<td>Female</td>
<td>26</td>
<td>14</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td>26.5 ± 5.7</td>
<td>24.4 ± 4.9</td>
<td>27.7 ± 6.1</td>
<td>0.11</td>
</tr>
<tr>
<td>ODI</td>
<td>1.8 ± 2.7</td>
<td>2.2 ± 3.2</td>
<td>1.4 ± 2.1</td>
<td>0.87</td>
</tr>
<tr>
<td>ASIA score*</td>
<td>2.4 ± 0.7</td>
<td>2.8 ± 0.5</td>
<td>2.1 ± 0.7</td>
<td>0.36</td>
</tr>
<tr>
<td>Known no. of levels fused</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thoracic</td>
<td>10.0 ± 4.7</td>
<td>10.3 ± 3.5</td>
<td>8.1 ± 3.8</td>
<td>0.47</td>
</tr>
<tr>
<td>Lumbar</td>
<td>2.6 ± 2.0</td>
<td>4.6 ± 1.1</td>
<td>1.0 ± 0.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>L5–S1 interbody fusion</td>
<td></td>
<td></td>
<td></td>
<td>0.089</td>
</tr>
<tr>
<td>ALIF</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Dura</td>
<td>83</td>
<td>43</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>OR time (minutes)</td>
<td>284 ± 287</td>
<td>296 ± 194.6</td>
<td>279 ± 141.6</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>EBL (mL)</td>
<td>1640 ± 1200</td>
<td>2480 ± 1020.2</td>
<td>1982.9 ± 1538.9</td>
<td>0.294</td>
</tr>
<tr>
<td>CLV (mm)</td>
<td>27 ± 6.9</td>
<td>17 ± 4.7</td>
<td>7.5 ± 2.8</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

*ASIA score: 1 = complete cord injury, 2 = incomplete cord injury, 3 = ASIA A, 4 = ASIA B, 5 = ASIA C, 6 = ASIA D, 7 = ASIA E

- OR: operating room
- ALIF: anterior lumbar interbody fusion
- Dura: dural tears
- EBL: estimated blood loss
- CLV: chest radiographic changes

No. = not applicable

The DURA sheet data included data from one additional case for completeness of data analysis.
Coronal balance with circumferential minimally invasive spinal deformity surgery for the treatment of degenerative scoliosis: are we leaning in the right direction?

Corey T. Walker, MD, Jakub Godzik, MD, Santiago Angel, Juan Pedro Giraldo, Jay D. Turner, MD, PhD, and Juan S. Uribe, MD

Department of Neurosurgery, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, Arizona

**TABLE 2. Surgical data for patients according to their coronal alignment subgroup**

<table>
<thead>
<tr>
<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>26</td>
<td>5</td>
<td>11</td>
<td>42</td>
</tr>
<tr>
<td>ALIF L5–S1</td>
<td>11</td>
<td>4</td>
<td>6</td>
<td>21</td>
</tr>
<tr>
<td>Mean segments fused</td>
<td>4.4</td>
<td>6.4</td>
<td>5.4</td>
<td>4.9</td>
</tr>
<tr>
<td>Long segment—thoracic to sacrum fixation</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>ACR</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Prior fusion</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Dextroscoliosis/levoscoliosis</td>
<td>12/14</td>
<td>2/3</td>
<td>6/5</td>
<td>20/22</td>
</tr>
<tr>
<td>Median curve apex</td>
<td>L2–3 disc</td>
<td>L2–3 disc</td>
<td>L1–2 disc</td>
<td>L2–3 disc</td>
</tr>
<tr>
<td>Postop CM</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

Data are expressed as the number of patients unless otherwise indicated. Type A patients had no CM, type B patients had a preoperative shift toward the concavity, and type C patients had a preoperative shift toward the convexity.
Thank you!

• UCSF Neurosurgery
  • Chris Ames
  • Mike Safaei
  • Alex Tenorio
  • Annette Molinaro
  • Yalan Zhang
  • Alex Haddad
  • Winward Choy
  • Joe Osorio
  • Praveen Mummaneni
  • Dean Chou
  • Sanjay Dhall

• UCSF Vascular Surgery
  • Chuck Eichler
  • Bian Wu

• UCSF Orthopedic Surgery
  • Alekos Theologis
  • Vedat Deviren
  • Sig Berven
  • Shane Burch
  • Bobby Tay
  • Serena Hu
Take Home Points:

- **Sagittal alignment and balance matters!!**
- Careful consideration of pre-operative Sagittal Profile:
  1. Thoracic hypokyphosis
  2. TL alignment
  3. Proximal thoracic hyper kyphosis
  4. Always consider PI
- Ample posterior column release in the form of wide facetectomies and Ponte’s osteotomies at the appropriate segments
- Differential Rod Contouring
- Large diameter CoCr rods (Match the implant with the patient)
- High implant density at the peri-apical segment
- Concave segment distraction for thoracic scoliosis and convex segment compression for lumbar scoliosis

Thank You
Disclosures

- Consultant
  - Depuy Spine, Alphatec, Stryker/K2M, Surgalign, SpineArt

- Research support
  - NIH/NHS/CDMI; Stryker/K2M

- Surgeon Advisory Board
  - Ullrich

- Educational content development
  - JBJS Inc.
Background

Extradural

Intradural

Extra-medullary

Intramedullary

NEUROSURGERY!!!!
Extradural Tumors

Goals of this talk
1) General principles of resection
   • Spinal Location
2) Reconstructive Options

What We Will Not Cover
1) Differential diagnoses
2) Indication for operations

Resection Principles

• Mobile spine
  • Primary
  • Metastatic

• Nonmobile spine (Sacrum)
  • Primary
  • Metastatic
Primary Tumors

Which Approach?

Weinstein-Boriani-Biagini (WBB) surgical system

Zone 4-9 = Anterior + Posterior
Zone 4-9 = Anterior + Posterior

Zone 3-10 = Posterior Only
Unilateral (Zones 1-6 or 7-12) = Anterior + Posterior

Where to cut discs?

• Evaluate Sagittal Images
Case Examples

- 60-year old male with mild mid back pain

- Biopsy: T9 Rhabdomyosarcoma (grade 2)

- Neoadjuvant radiation → tumor growth

- Plan?

Discectomies?

T8-T9 and T9-T10
17yo Clear Cell Chondrosarcoma
Special Considerations

- Cervical tumors

- Vertebral artery sacrifice? —> Vertebral artery occlusion test

- Cervicothoracic/upper thoracic tumors

Manubriotomy

Sternotomy

High Thoracotomy

Approach

S3 and Above
Anterior → Posterior

Below S3
Posterior-only
**Soft Tissue Coverage**

<table>
<thead>
<tr>
<th>Sacrectomy Type</th>
<th>Nerve Roots Sacrificed</th>
<th>Flap Closure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>Bilateral S1 and below</td>
<td>VRAM</td>
</tr>
<tr>
<td></td>
<td>Bilateral or unilateral L5</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>Bilateral S2 and below</td>
<td>VRAM</td>
</tr>
<tr>
<td></td>
<td>Unilateral S1 and S2 and below</td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td>Bilateral S3 and below</td>
<td>Local</td>
</tr>
<tr>
<td>Low</td>
<td>Bilateral S4 and below</td>
<td>Local</td>
</tr>
<tr>
<td>Distal</td>
<td>S4 and above preserved</td>
<td>Local</td>
</tr>
</tbody>
</table>

**VRAM**

**Local vs. free flap**

* Keystone  
* Unilateral pedicled superior gluteal artery
Stabilization

**S3 and Above**
Stabilization bc SI joint disrupted

**Below S3**
No stabilization required

---

**Case Example #1**

56-year old female; chordoma; no mets

Negative Margins
Case Example #2

67 year old male; healthy, chordoma; no mets

VRAM
Case Example #3

24yo M
Osteosarcoma
No mets
Negative Margins
Metastatic Disease
Resection Principles
Invasiveness?

- Posterior decompression/stabilization only
  - Posteriorly-based met
  - Ventral met
    - Mechanical instability predominant with no/minimal ventral neural compression
    - Preserved sagittal alignment (no kyphosis)
  - Prior radiation
  - Limited life expectancy
- Corpectomy
  - Ventral met
  - Kyphosis
  - “Radioresistant” tumor
  - No prior radiation
- Separation surgery

Thoracic Met - Corpectomies

Anterior (thoracotomy) → Posterior

Posterior → Posterior
T3 + T4: Met Lung Cx

Lumbar Met - Corpectomies

- Direct Lateral
- Open Anterolateral
- Direct Anterior
- Posterior only (no corpectomy)
L3: Met Breast Cx

Reconstruction

Anterior Column Reconstruction

- Structural Support
  - Material
  - Modularity

Posterior Column Reconstruction

- Screws
  - Material
  - Approach (open vs. perc)

- Rods
  - Material
  - Number
## Anterior Column Reconstruction

<table>
<thead>
<tr>
<th>Not a Cage</th>
<th>Cage</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMMA</td>
<td>Radiolucent</td>
</tr>
<tr>
<td>Osseous</td>
<td>Metallic</td>
</tr>
</tbody>
</table>

### Modularity of Cage

- Static
- Expandable
- Rectangular

- Expandable
## Posterior Column Stabilization

<table>
<thead>
<tr>
<th>Pedicle Screws</th>
<th>Rods</th>
</tr>
</thead>
<tbody>
<tr>
<td>*** At least 3 above and 3 below ***</td>
<td>*** No corpectomy = 2 ***</td>
</tr>
<tr>
<td>*** Corpectomy = 3 or 4 ***</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metallic</th>
<th>Radiolucent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium</td>
<td>Carbon Fiber PEEK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metallic</th>
<th>Radiolucent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium</td>
<td>Carbon Fiber PEEK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Open</th>
<th>Perc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neural decompression</td>
<td>Only stabilization Needed</td>
</tr>
<tr>
<td>Sacral lesions</td>
<td></td>
</tr>
</tbody>
</table>

---

Radiolucent Carbon Fiber–Reinforced Pedicle Screws for Treatment of Spinal Tumors: Advantages for Radiation Planning and Follow-Up Imaging

Florian Ringel ¹, Yu-Mi Ryang ², Jan S Kirschke ³, Birgit S Müller ⁴, Jan J Wilkens ⁴, Jeremy Brodard ², Stephanie E Combs ⁵, Bernhard Meyer ²

**Conclusions:** Carbon fiber–reinforced PEEK pedicle screws reduce image artifacts on computed tomography and magnetic resonance imaging. Thereby, they are a valuable and feasible option for spinal instrumentations in patients harboring spinal tumors where postoperative imaging and radiation therapy planning are necessary and might be crucial for long-term outcome and overall survival.
Biomechanical effects of posterior pedicle screw-based instrumentation using titanium versus carbon fiber reinforced PEEK in an osteoporotic spine human cadaver model

Findings: Regarding maximum axial force (group A: 2835 N, group B: 3006 N, p = 0.595) and maximum compression (group A: 11.67 mm, group B: 15.15 mm, p = 0.174) no statistical difference could be shown between the two groups. However, significant smaller cavity formation around the pedicle screws could be observed in group B (p = 0.007), especially around the screw tip (p < 0.001).

Interpretation: Carbon fiber reinforced PEEK devices seem to be advantageous in terms of microscopic screw loosening compared to titanium devices.

Pedicle screw anchorage of carbon fiber-reinforced PEEK screws under cyclic loading

Conclusions: Using nonmetallic CF/PEEK instead of standard titanium as pedicle screw material did not affect screw loosening in the chosen test setup, whereas cement augmentation enhanced screw anchorage of CF/PEEK screws. While comparable to titanium screws in terms of screw...
Post-Op MRI

Cage Level

Screw Level

My Preferences...An Evolution

Generation 1
(First year of practice)

All titanium

T9 Leiomyosarcoma (en-bloc)
My Preference...An Evolution

Generation 2
(2nd year of practice)

- **Anterior column**
  - PEEK

- **Posterior column**
  - Screws: titanium
  - Rods: titanium

Metastatic lung cancer (2-level VCR)

My Preference...An Evolution

Generation 3
(3rd year of practice)

- **Anterior column**
  - PEEK

- **Posterior column**
  - * Screws: all titanium except screws adjacent to corpectomy, which are PEEK
  - * Rods: titanium

Metastatic breast cancer (1-level VCR)
My Preference...An Evolution

Generation 4
(4th year of practice)

Anterior column
PEEK

Posterior column
* Screws: all titanium except screws adjacent to corpectomy, which are PEEK

* Rods: PEEK

Spindle cell sarcoma (15yo; 2-level en-bloc)

Sacral Mets (Perc stabilization)

Multiple myeloma
Met Renal Cell

Finito!
Surgeon Preservation and Patient Safety

David L. Skaggs, MD, MMM
Director Spine Center of Excellence
Executive Vice-Chair Orthopaedics
Director Pediatric Orthopaedics
Cedars-Sinai Medical Center

---

Musculoskeletal Disorders Among Spine Surgeons

Results of a Survey of the Scoliosis Research Society Membership
Spine, 2011

<table>
<thead>
<tr>
<th>Condition</th>
<th>Spine Surgeons</th>
<th>General Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>rotator cuff disease</td>
<td>24%</td>
<td>5%</td>
</tr>
<tr>
<td>Lateral epicondylitis</td>
<td>18%</td>
<td>2%</td>
</tr>
<tr>
<td>neck pain</td>
<td>59%</td>
<td>20%</td>
</tr>
<tr>
<td>neck pain with radiculopathy</td>
<td>3%</td>
<td>0.01%</td>
</tr>
</tbody>
</table>

---

Carpal Tunnel Syndrome in Spine Surgeons: A Pilot Study

Linda Fox, MD, MPH, MS; Lee Freedman, Ph.D.; David Shapiro, MD

- 32% carpal tunnel syndrome interfered with their work,
- 10% of surgeons with carpal tunnel syndrome stopped operating temporarily
Surveys OTA, NASS, Hip Society, POSNA

- High rates of neck & arm overuse injuries
- Surgeon time off work from injuries
- Recommend use of power instead of manual tools

JCO, 2016
J Arth, 2016
J Orthop Trauma, 2016
Arch Env Occ Health, 2007

I Started Power in 2007 to Protect Me

I now use it to Protect My Patients
10,000 hours working construction
Culture of protecting your body
Power is your friend

2.0 mm flexible drill bit
Slow rotation maximizes proprioception

3.0 mm dull threaded reamer

Pedicle screw

NO TAP! Want to Dilate pedicles, not cut threads
Flexible Drill bit bends as it encounters hard cortical bone, and self-centers into soft cancellous bone.

“soft hands” allow bit to Self-Center. Guide into the soft cancellous channel.

Sometimes Right On Target, Sometimes Skive Off Pedicle Wall.
Results – similar safety and revision

99.9% of pedicle screws placed with power pedicle preparation did not have complications or revision.

<table>
<thead>
<tr>
<th></th>
<th>Manual</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screws</td>
<td>9,424</td>
<td>22,209</td>
</tr>
<tr>
<td>Screws Revised</td>
<td>0.07%</td>
<td>0.02%</td>
</tr>
<tr>
<td>P</td>
<td>P&lt;0.02</td>
<td>P&lt;0.02</td>
</tr>
<tr>
<td>Transient Neuro (patient)</td>
<td>0.5%</td>
<td>0.07%</td>
</tr>
<tr>
<td>Vascular Injury</td>
<td>0</td>
<td>1?</td>
</tr>
</tbody>
</table>

99.9% of pedicle screws placed with power pedicle preparation did not have complications or revision.

These data call into question the routine use of expensive, time consuming navigation systems.
**Power 32% Less Flouro than Manual**

- Better “feel”, less need for fluoros
- P<0.01

Spinal Deformity, 2015

**Type D pedicles- Stiff drill bit 2.7 – 3mm (flexible drill bit skives off)**

Type D pedicles can get the “tough” pedicles

CT + Robot = “4mm pedicles too small for screws”

Revised with Power technique

Implant pullout

No screws T3-T10

16

17

18
Screw Wobble – effects bone/screw interface

FREEHAND (blue) vs POWER (red) – Screw Wobble

Early Clinical Series
Power 4 times Less Screw Failure better than Manual

- Manual 0.8% (8/948)
- Power 0.1% (2/1410)
- P=0.02
Cedars Sinai Spine Center

Manual vs. POWER Screw Insertion

EMG

POWE

R

Safe range

20%

Load applied to patient during T8 bilateral screw insertion

- Power: 8-10Lbs
- Manual: 25-30Lbs
- 70 Lbs!

Cadaver Study: Less Pedicle Breaches with Power

• 3 surgeons new to power
• >200 screws cadavers
My experience: power protects surgeon from overuse injuries

Challenging path to commercialization and FDA approval
- Pitched to top spine companies – KOLs said too dangerous
Protect Rotator Cuff – Prevent Forceful Plunging
Arms Braced Against Patient and Surgeon’s Body
Shoulder Abducted
BAD (for surgeon and patient)
Good

Ultrasonic Bone Cutting Tool
- Less force (for patient and surgeon)
- Less bleeding
- Cuts bone, not soft tissue**
- Feel more resistance at bevel

Fingers too far from tip
- Hold like pencil
- Fingers close to tip
- Rubber tip prevents finger burn
Through Previous Fusions

Cedars Sinai Spine Center

120 pediatric spine surgeries
posterior osteotomies (113)
laminectomies (4)
foraminotomies (2)
partial sacrectomy (1)
vertebrectomy (2)

Conclusions:
No Complications
Less surgeon effort/fatigue
Better “feel”

1. Mentor Young Surgeons to Preserve their Bodies
2. Intuitive Less Force Improves Patient Safety
Rotate Fluoroscopy
(sometimes many angles)
Tips don’t Cross
Tips within bone

Left, Concave Rod
Share Load with serial reducers
Apex Vertebrae
Convex
Concave

De-rotation: Differential Rod Bending
Apex Vertebrae
Convex
Left
Concave
Right
Concave
EnBloc Derotation:
Double Curve: Apex Vs. Apex
Single Curve: Apex Vs. End Vertebrae

Dual Rods
Rods Bend Less
Apex Vertebrae

Convex

Concave

Screws Pointing Forwards = De-rotation Effective
No Osteotomies

Parallel Rods = Effective Derotation

Produce kyphosis
Patients Report Derotation Improves Chest Asymmetry
Plastic Adhesive Closure

$100-150 / case
Remove at 2-3 weeks

Tethering: Advance or Bandwagon?
Marketing?

14 yo, Risser 4
Left Shoulder High

Did this child need surgery?

IMAST Best Paper – 2021
HARMS STUDY GROUP – Thoracic Curves
Anterior Vertebral Body Tethering
Versus Posterior Spinal Fusion

<table>
<thead>
<tr>
<th></th>
<th>Tether</th>
<th>PSF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual Thoracic Cobb &gt;35°</td>
<td>26%</td>
<td>1%</td>
</tr>
<tr>
<td>Revision Rate</td>
<td>16%</td>
<td>2.5%</td>
</tr>
<tr>
<td>SRS-22 post-op self image score Lower (p&lt;0.05)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Peter O. Newton, MD; Stefan Parent, MD, PhD; Firoz Miyani, MD; Ahmet Alanay, MD; Baron Lonner, MD; Kevin M. Neel, MD; Daniel Hoemdeschmeyer, MD; Burt Yaszay, MD;
Thank You
Conservative Management of Early-Onset Scoliosis

Graham Fedorak, MD, FRCSC
Assistant Professor, University of Hawaii

Disclosures

- None
Acknowledgements

- Jacques D’Astous, MD
- Michael Pond, PA

Same neighborhood, both getting casted…EOS in the water??? (or, hammer nail???)

INITIAL CLINICAL & RADIOGRAPHIC ASSESSMENT
Clinical Assessment of EOS

- Be thorough – “idiopathic” is diagnosis of exclusion
- Be persistently suspicious of their “idiopathicness” – CT disorders, genetics consult

C-EOS Classification

- Williams et al 2014
- < 10 years of age
- Idiopathic
- Neuromuscular
- Syndromic
- Congenital
- Cobb/Kyphosis/APR
When to get an MRI

- NAA in 13-26% of presumed idiopathic EOS
- Dobbs JBJS 2002 (n=46)
  - 22% with Cobb > 20
  - 8/10 required NSx
- Kouri et al 2018 (Lexington)
  - 39% Cobb ≥29.5° (13/33)
  - 0% Cobb <29.5° (0/20)
- If treating, get it

True story, “fell out of a coconut tree” while a child in Samoa

Congenital EOS

- Kidneys (MRI will see, or, US)
- Cardiology consult/echo
  - I have had a healthy child with an isolated hemi who needed open heart surgery.
  - So I continue to consult as I was taught.
PREDICTING PROGRESSION IN IDIOPATHIC - EOS

Remember - Scoliosis < 1 year often gets better

- 92% resolution in a series of 100 children, most presenting before one year of age
- Children presenting at < 1 year had 90% chance of curve regression
- Children presenting > 3 years of age had virtually no chance of curve regression
- I would view this as a continuum
Idiopathic EOS - Deciding on Treatment - RVAD (Mehta’s angle)

Rib Vertebral Angle Difference

RVAD = angle concavity-angle convexity
eg  = 70° - 60° = 10°

Phase (rib-vertebra relationship)

A measure of rotation – apical vertebrae, convexity

Phase 1

Phase 2 all progressive
Risk of Progression

- Low risk
  - Cobb < 20°
  - RVAD < 20°
  - Phase 1 rib
- High risk (80% progression)
  - Cobb ≥ 20°
  - RVAD ≥ 20°
- Phase 2 rib (highest risk group)
- Thoraco-lumbar curve

Observe vs Treat – Not Sure?

- Phone a friend
- Still not sure? Don’t wait 6 months to figure it out!
- See them back in 3-4 months if observing (and v. young)
CONSERVATIVE TREATMENT IS THE FOUNDATION OF MANAGEMENT OF EARLY-ONSET SCOLIOSIS

Delay is your Friend in Growth
Friendly Surgery (sometimes)

- Start early, more surgeries
- Bess, JBJS 2010
  - 13% decrease in complications for every additional year of age with TGR
- Upasani, JPO 2016
  - VEPTR – 41% higher compds < 3 yrs vs 3-6
- Sometimes early surgery is the best choice, ie isolated hemi-vertebrae
Cast versus Brace Treatment

- Less than 1 year – sometimes brace first unless ++robust++
- NON-IDIOPATHIC - Complex discussion – I think casting is better but caveats!
- Smarttots.org – current state of brain dev literature
Cast versus Brace Treatment

- If we feel treatment is warranted, we recommend casting
- Greater correction
- Guaranteed compliance

Serial CAD/CAM Bracing: An Alternative to Serial Casting for Early Onset Scoliosis

John Thometz, MD and Xue-Cheng Liu, MD, PhD

- N=9, mean age 11 months (4-24)
- Mean scoliosis 45° (+/- 9)
- Mehta style forces applied, CAD/CAM brace fabrication
44% scoliosis $\leq 10^\circ$ (4/9) at mean 3.4 y

Other five?
- Initial: 47° (30-60°)
- Final: 28° (14-38°)

YOUNG cohort, short follow-up (FU measured from start of treatment)

“Among 9 patients, each one had, on average, 2 casts [0-5] applied before… [bracing]”

And…braces were molded under general anesthesia!

Very YOUNG cohort, results not as good as casting at shorter FU, still need a GA, getting some casts anyways.
CAST TREATMENT OF EOS

Why Do I Cast???

Better Results!!!
(\textit{for idiopathics for sure})
Casting – Advantages

- Greater forces applied
- Better molding
- Better correction
- Better compliance
- Bracing better tolerated after casting

Casting – Disadvantages

- General anaesthetic
  - Yes, some folks do this awake and have reported it, Kawakami; PSSG study 2020 (LaSalva et al)
  - Their results aren’t as good …
- Can’t bathe, hot, can’t inspect skin, can’t hug child, can’t go beach
Casting Results – Mehta

“Success” = <10°

- Mehta JBJS-Br 2005: n=136
- Mean age to start 22 months, FU a mean of 10 years + 10 months
- “Success”: 69% (94):
  - 19 months (6-48 months), 32° (11-65°)
  - “Reduced but not reversed deformity”: 31% (42)
  - 30 months (11-48 months), 52° (23-92°)

Minimum 5-Year Follow-up of Mehta Casting to Treat Idiopathic Early-Onset Scoliosis

- N=38, mean 8 years FU (5-13)
- First cast:
  - Age: 24 +/- 15 months;
  - Cobb: 56° +/-20°

- Final Follow-up:
  - 49% scoliosis ≤15°
  - 73% improved at least 20° (from pre-treatment)
Case

- 8 month female
- Progressive EOS
- Cobb 52°
- RVAD 40°, P2 rib
- Plan?

Case

- 11 months, first cast
- Very flexible
Case

- 6 casts over 14 months
- 25 months old
- Cobb 12°
- TLSO 1 year

Case

- 6 casts over 14 months
- 22 months old
- Cobb 12°
- TLSO 1 year

- Final FU at age 10
Age Stratified Outcomes of Mehta Casting in a Large Multi-Center Cohort of Idiopathic Early-Onset Scoliosis Patients

- **POSNA 2020** - Retrospective review of Mehta casting from 2000-2016
- Minimum 2 years FU **AFTER** end of casting
- 5 Shriners Hospitals
  - Salt Lake City, Greenville, Chicago, Sacramento, Philadelphia

### Numbers

- **331** patients casted during study period
- 99 excluded < 2 years FU after casting
- 12 excluded for other criteria
- 75 excluded – NON-idiopathic EOS
Idiopathic EOS Cohort

- **138** children with idiopathic EOS
  - < 18 month = 60
  - 18-24 months = 30
  - 2-3 years = 21
  - 3-4 years = 13
  - > 4 years = 14

Idiopathic EOS Cohort

- **138** children with idiopathic EOS
- Mean 5.1 years follow-up (2.1-12.3 years)
- Initial Scoliosis: **51°** (22-109°) (NS all groups)
### Table

<table>
<thead>
<tr>
<th>Sex (M:F)</th>
<th>39:21</th>
<th>13:17</th>
<th>25:8</th>
<th>Initial RVAD (deg.)</th>
<th>31.7 (5.3)</th>
<th>31.1 (5.0)</th>
<th>32.8 (13.0)</th>
<th>32.8 (13.0)</th>
<th>56.7 (15.6)</th>
<th>50.4 (18.6)</th>
<th>15.7 (2.4)</th>
<th>15.5 (2.2)</th>
<th>15.5 (2.2)</th>
<th>15.5 (2.2)</th>
<th>15.5 (2.2)</th>
<th>15.5 (2.2)</th>
<th>15.5 (2.2)</th>
<th>15.5 (2.2)</th>
<th>15.5 (2.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curve (L:R)</td>
<td>40:984</td>
<td>0.2818</td>
<td>0.3182</td>
<td>Initial RVAD (deg.)</td>
<td>31.7 (5.3)</td>
<td>31.1 (5.0)</td>
<td>32.8 (13.0)</td>
<td>32.8 (13.0)</td>
<td>56.7 (15.6)</td>
<td>50.4 (18.6)</td>
<td>15.7 (2.4)</td>
<td>15.5 (2.2)</td>
<td>15.5 (2.2)</td>
<td>15.5 (2.2)</td>
<td>15.5 (2.2)</td>
<td>15.5 (2.2)</td>
<td>15.5 (2.2)</td>
<td>15.5 (2.2)</td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td>17.3 (1.9)</td>
<td>17.2 (1.9)</td>
<td>16.4 (2.0)</td>
<td>15.7 (2.4)</td>
<td>16.4 (2.0)</td>
<td>15.7 (2.4)</td>
<td>16.4 (2.0)</td>
<td>15.7 (2.4)</td>
<td>16.4 (2.0)</td>
<td>15.7 (2.4)</td>
<td>16.4 (2.0)</td>
<td>15.7 (2.4)</td>
<td>16.4 (2.0)</td>
<td>15.7 (2.4)</td>
<td>16.4 (2.0)</td>
<td>15.7 (2.4)</td>
<td>16.4 (2.0)</td>
<td>15.7 (2.4)</td>
<td></td>
</tr>
<tr>
<td>Age at first cast (years)</td>
<td>11.0 (2.3)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td>11.7 (2.9)</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>&lt; 18 months (n=60)</td>
<td>60</td>
<td>30</td>
<td>13</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
</tbody>
</table>

### Graph

If you remember one slide:

- Mean scoliosis FEU: 11.1° (14.6°)
- Scoliosis < 15° 72.4%
- Improved ≥ 20° + 84.2%
- Scoliosis < 30° 83.3%
- Surgery or scoliosis > 50° 8.3%
- Scoliosis > 30° 84.2%
- Improved ≥ 20° + 72.4%
### 18-24 months (n=30)

- **Scoliosis FFU:** 24.2˚ (26.0˚)
- **Scoliosis < 15˚:** 35.7%
- **Improved 20˚+:** 57.1%
- **Scoliosis < 30˚:** 70%
- **Surgery or scoliosis >50˚:** 23.4%

### 2-3 years (n=21)

- **Scoliosis FFU:** 23.7˚ (16.6˚)
- **Scoliosis < 15˚:** 33.3%
- **Improved 20˚+:** 52.4%
- **Scoliosis < 30˚:** 61.9%
- **Surgery or scoliosis >50˚:** 23.4%
3-4 years (n=13)

- Mean scoliosis FFU: 34.6° (38.2°)

<table>
<thead>
<tr>
<th>Scoliosis</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;50°</td>
<td>64.3%</td>
</tr>
<tr>
<td>21-49°</td>
<td>21.4%</td>
</tr>
<tr>
<td>15-20°</td>
<td>35.7%</td>
</tr>
<tr>
<td>≤15°</td>
<td>7.1%</td>
</tr>
</tbody>
</table>

- Surgery or scoliosis: 64.3%
- Scoliosis > 30°: 21.4%
- Improved 20°: 35.7%
- Scoliosis > 15°: 7.1%

< 4 years (n=14)

<table>
<thead>
<tr>
<th>Scoliosis</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;50°</td>
<td>30.8%</td>
</tr>
<tr>
<td>30-49°</td>
<td>46.2%</td>
</tr>
<tr>
<td>15-29°</td>
<td>21.4%</td>
</tr>
<tr>
<td>≤15°</td>
<td>7.1%</td>
</tr>
</tbody>
</table>

- Mean scoliosis FFU: 32.6° (17.4°)
- Surgery or scoliosis: 30.8%
- Scoliosis > 30°: 46.2%
- Improved 20°: 35.7%
- Scoliosis > 15°: 7.1%
Summary of Principles

- Mehta/EDF Casting is most effective in younger children and smaller scoliosis
  - Ideal is < 18 months of age
  - 18-24 months was same as 2-3 years

- YET...which child responds to casting can be surprising – give them a chance

The How of Casting

- Le Mesurier
- 1941 Hospital for Sick Children, Toronto
Types of Casts

- Risser casting – of historical interest at this point
- Alternatively Repetitive Cast and Brace Treatment – ARCBT – N. Kawakami, SRS 2018; JPO 2018
- Mehta/EDF Casting (Elongation, Derotation, Flexion)

EDF Casting - Biomechanics

- **Elongation** - Longitudinal force (pelvic girdle & occipito-mandibular)
- **Derotation** - Transverse & derotational forces (ribs, erector spinae m.)
- **Flexion** – Lateral flexion to decrease scoliosis
- Materials
  - Plaster unsurpassed moldability
  - Fiberglass over wrap for strength
EDF Casting – History 1964

La technique de l’E. D. F. dans la correction des scolioses
par
Yves COTREL et Georges MOREL

Team Approach

Key

- Can be more stressful for anesthesia – have them talk with other anesthesiologists with experience casting

- Team approach – they need to know when to hustle and when to abort
Shriners Salt Lake Casting Table
Rob Eldridge, Michael Pond

Shriners SLC Casting Table
MacGyver Your Own Table

Three Solutions to a Single Problem
Alternative Casting Frames for Treating Infantile Idiopathic Scoliosis
Matthew A. Hulanski, MD,* Benjamin L. Harper, MD,†
Jeffry A. Cassidy, MD,‡ and Huwmi Ch Crawford, FRACS§

J Spinal Disord Tech 2013:26:274–280

REMEMBER THE EPISODE WHEN I COULDN'T FIGURE OUT HOW TO SOLVE A PROBLEM USING THE THINGS I HAD ON HAND?

YEAH, ME NEITHER

Materials
EDF Casting – Technique

- Casting table
- 2 layers of stockinette (silver impregnated t-shirt)
- Minimal webril, but extra felt pads where needed
- Traction head halter & pelvic band
  - 1/3-1/2 body weight
- 4 layers of plaster sheets, plaster rolls
- Mold it.
- Fiberglass overwrap
- Generous thoracic & abdominal windows, with anterior flanges)
- Posterior derotation window

Eyes, ears, bite block, decompress stomach
Pelvic Traction

Head Halter; arms asymmetric to promote lateral flexion
EDF Casting – Technique

3 point mold
Risser

Derotation
EDF cast
- Stopped shoulder straps 2018 after study showing no difference
- Kids/families happier – faster cast application (cut-outs easier), correction seems same

Optimization of Casting in Early Onset Scoliosis. JPO 2019

“Le D’Astous” (SLC, above)

“The Stasi’astous” (current SLC, below)

“The Stasikelis” (Greenville, above)
Frequency of Cast Changes

- q 2 months if 2 years (i.e. < 3 )
- q 3 months if 3 years
- q 4 months if 4 years or older

From Mehta, seems to work.

When to Stop?

- Anecdote guides this

- Upright x-ray PRIOR to cast application roughly q 6 months; can be out of cast 2-3 days – this is guided growth

- IF, $\leq 10^\circ$, mold TLSO during last cast application
  - ish… so many variables
EDF Style TLSO’s

When to stop if you don’t “win”?

- Nobody knows – all anecdote – highly dependent on child, family, surgeon, age

- Strongly urge families to give it a year, get a sense of change;
- **Assess in 6 months chunks, not every cast**
- No “cast holidays” in first year (idiopathic) (18 months better)
What is the Cost of a “Cast Holiday” in Treating Children with Early Onset Scoliosis (EOS) with EDF/Mehta Casting?

- JPO 2020
  - n=90 w/ 2 yrs (all SLC), 31 took “holiday” in first 18 months

- Cast holiday first 18 months associated with lower chance of “cure” and greater scoliosis

What About Non-Idiopathic?

- ICEOS 2019 Pahys et al – Shriners cohort
  - 75 NI-EOS, min 2 yrs, avg 5 years FU

- 9% scoliosis < 15° at final FU
- 15% improved > 20°
- Scoliosis > 50° - 65%
  - 44% (of entire cohort)surgery at mean 7.5 y
What About Non-Idiopathic?

- Worth a try
- Delay has huge value – **mean age of surgery was 7.5 years in our cohort**
- More data and critical appraisal of outcomes in this population needed

Summary

- Casting can resolve scoliosis in 30-70% of idiopathic EOS and a much smaller percentage of non-idiopathic EOS
- **AGE you start treatment is key**
- In most cases can delay need for surgery, regardless of etiology
Summary

- Growth is the corrective force in conservative treatment of EOS
- **Don’t wait** – earlier treatment is better
- Fri. Sept 3 AAOS – ICL “From Mehta Casts to Magnetic Rods”

Mahalo!
Cervical Deformity Assessment & Reconstruction Options

Dan Riew, MD
Professor, Orthopedic Surgery, Columbia University
Professor of Orthopedic Surgery in Neurological Surgery Departments,
Columbia University and Weill Cornell Medical College

Disclosures:
Royalties: Biomet, Nuvasive, Happe

Stocks: Osprey, Expanding Orthopedics, Spinal Kinetics, Amedica, Vertiflex,
Benvenue, Paradigm Spine, PSD, Spineology, Axiomed

Deputy/Associate Editor: Global Spine J, Spine, Neurosurgery, Neurospin
Orthopedics Today, Clinics in Orthopaedics, Spine Surgery Today

Board: NASS
Cervical Deformity Assessment

Step 1

- Flexible
- Fixed

Compare Supine or MRI vs Standing
Cervical Deformity Assessment

Step 2

• Cervical correction
• C-T correction
Kyphosis Correction
For Cervical-alone Re-alignment
Basion-C2 tip (ear) line posterior to sternum

For Cervical-alone Re-alignment
Basion-C2 tip line posterior to sternum

Focal kyphosis with normal upper thoracic spine
Kyphosis, Myelo-Radiculopathy

C-T Correction
Basion-C2 tip line Anterior to sternum

Neutral Cervical Spine with Upper Thoracic Kyphosis
Needs Posterior Correction to Upper Thoracic
Lordotic C-Spine; Kyphotic T-Spine; Hyperlordotic L-Spine

Assessment & Significance of Global Sagittal Alignment

- Interplay of C-T-L spines
- Measurements
- Assessments
Correlation: C2-C7 SVA & NDI

Poor Correction of Upper Thoracic Spine
T1 Slope

- T1Slope: Slope of ground
- C2-7 SVA: compensated?
Thoracic Kyphosis: Compensatory Cervical Hyper-lordosis
Posterior Osteotomy
Neck & Back Pain

Lumbar Hyperextension

L-Spine Hyperextension Corrected
Back Pain Improved
Cervical Osteotomy: Indications

Does it bother the patient?

Congenital Deformity, Neck Pain, Radiculopathy
No Correction, Decompression, Fusion
Not all deformities need correction

Klippel-Feil, Hemivertebra
Osteotomy

• SPO: C-T or T
• PSO: C-T or T
• A/P

Ankylosing Spondylitis
• >80° Correction
• Soft Collar
• Coronal + Sagittal Correction

Failed Multiple Anterior & Posterior Operations
• Pseudarthrosis
• Kyphoscoliosis
• Skull Plate Pullout
PSO C4 & C7: Protect Vertebral Artery

PSO C4, C7

Revision Occ-T4
Fused C3-5 s/p C4-6 Lami for astrocytoma at 15

2 hrs 45 min EBL: 125cc

- CP
- s/p ACDF
- Posterior fusions
- Infection, wound dehiscence
- Minor Trauma - Collapse
Partial Correction

C6 & C7 Osteotomy

Anterior: 2 Hr 45 Min
Posterior: 2 Hr 35 Min
Blood Loss: 375 cc
Comparison of SPO vs. PSO vs. Anterior Osteotomy for the Correction of Cervical Spine Deformities

<table>
<thead>
<tr>
<th>Osteotomy Type</th>
<th>Time (Hr:Min)</th>
<th>EBL (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedicle Subtraction</td>
<td>5:44</td>
<td>712</td>
</tr>
<tr>
<td>Anterior + Smith Petersen</td>
<td>5:21</td>
<td>325</td>
</tr>
<tr>
<td>Smith Petersen</td>
<td>3:50</td>
<td>232</td>
</tr>
<tr>
<td>Anterior + Posterior Fusion</td>
<td>3:26</td>
<td>183</td>
</tr>
</tbody>
</table>

6 Prior Operations
VA Injury
C7 Pedicle Subtraction

- Anterior osteotomy
- Posterior instrumentation
Problems w/ PSO

- 1-Level correction
- C2-7 SVA
- Bloody
- Blind maneuvers

62° Correction POD #1

Ankylosing Spondylitis PSO
Displaced

Plate Augmentation
Anterior: 1 hrs 55 min
Posterior: 3 hrs 30 min
EBL: 250cc

Anterior - Multi-level Osteotomy
Normal Appearing Spine
<table>
<thead>
<tr>
<th></th>
<th>Preop</th>
<th>Postop</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2-7 SVA</td>
<td>6.5cm</td>
<td>3.8cm</td>
</tr>
<tr>
<td>C2-7 Lordosis</td>
<td>-7.2°</td>
<td>20.1°</td>
</tr>
<tr>
<td>C7-SVA</td>
<td>-6.1cm</td>
<td>0.5cm</td>
</tr>
<tr>
<td>TK</td>
<td>61.0°</td>
<td>38.1°</td>
</tr>
<tr>
<td>LL</td>
<td>56.4</td>
<td>44.5°</td>
</tr>
</tbody>
</table>

Ankylosing Spondylitis
Psoriatic arthritis
Positioning
Anterior Osteotomy
Anterior Osteotomy

Remove Pillow
Distract & Simultaneously Push on the Forehead
Smith Petersen Osteotomy

Cranial

Caudal

Smith Petersen Osteotomy

Cranial

Caudal
Smith Petersen Osteotomy

Cranial

Caudal

Smith Petersen Osteotomy

Rod Compressor

Cranial

Caudal
Smith Petersen Osteotomy
• C2-4 facets fused
• C3-7 discs fused
• T2 distally fused

Cor + Sag Correction
Multiple Osteotomies
Power of Anterior Osteotomy

Anterior: 2 hrs 15 min
Posterior: 2 hrs 45 min
EBL: 200cc

Anterior Fusion by OPLL
Posterior Facets Solidly Fused Bilaterally w/ Instrumentation

Left  Mid  Right
How do you know if the correction is adequate?

Inter-Spinous Process Distance: A Novel Parameter Predicting Segmental Lordosis in Posterior Approach for Cervical Spine Deformity Surgery

*Eur Spine J. 2019 May;28(5):1192-1199 Shimizu, Saidon, Pongmanee, Riew*
<table>
<thead>
<tr>
<th>Gender</th>
<th>Cut-off ISPD</th>
<th>Estimated Segmental Lordosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5/6</td>
<td>10 mm</td>
<td>-5.4 ± 5.3°</td>
</tr>
<tr>
<td>C6/7</td>
<td>15 mm</td>
<td>-8.6 ± 4.9°</td>
</tr>
<tr>
<td>C7/T1</td>
<td>Male 15 mm / 20 mm</td>
<td>-8.0 ± 5.0° / -5.1 ± 5.0°</td>
</tr>
<tr>
<td></td>
<td>Female 15 mm</td>
<td>-5.3 ± 4.3°</td>
</tr>
<tr>
<td>T1/T2</td>
<td>Male 15 mm / 20 mm</td>
<td>-1.7 ± 4.2° / -0.0 ± 4.2°</td>
</tr>
<tr>
<td></td>
<td>Female 15 mm</td>
<td>-3.3 ± 3.5°</td>
</tr>
</tbody>
</table>

Estimated lordosis is presented as a value predicted based on linear regression model ± root mean square error
ISPD: inter-spinous process distance

Use Cables / Wires to Lordose Spine
Tips for Deformity Correction:

1. Positioning
2. Positioning
3. Positioning
Post Anterior

Positioning
Posterior Osteotomy
Maximal Extension
Head Close to Top of Bed

Conclusion: Anterior Osteotomy

- Faster, less blood loss vs PSO
- Gentle controlled correction
- Breaks fusion mass at facets
- Can be at any subaxial level
- Multi-level correction
- Can bend a fused spine with instrumentation
Thank You
When to Use 3 Column Osteotomies vs Multiple Posterior Column Osteotomies

Alexander Tuchman, MD
Assistant Professor, Cedars-Sinai Department of Neurosurgery
UCSF Pediatric and Adult Spine Surgery Course, 8/4/2021-8/7/2021

disclosures

• None
PCO vs. 3CO

- 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
      - 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
      - Deformity correction is through the unfused disc space and ALL is left intact

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

---

Posterior Column Osteotomies (PCO)

- **Effective**
  - Thoracic PCO increased ROM
    - Flexion-extension: 33%, 56%, 69% for 1-, 2-, or 3-level
    - Axial Rotation: 16%, 29%, 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)
- Vertebral Column Resection (VCR) (type 5)
- Multilevel Vertebral Column Resection (type 6)

Blood loss
- 643-2984 mL average EBL for PSO
- 900-6680 mL average EBL for VCR

Neurologic Injury
- New neurologic deficit rates after 3CO reported between 8.6%-40.3%
  - Scoli-Risk 1 (75% 3CO) → 22.18% neurologic decline from baseline at discharge
- Pseudoarthrosis
  - 10% pseudoarthrosis rate for PSOs
  - Up to 27% implant failure
    - Improved with supplemental rods

References:
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

66 yo woman with 10 previous lumbar surgeries

CB: 13 cm to the left
T10-L3: 61°
SVA: +33 cm
T10-L3: 73° kyphosis
Flexibility
66 yo woman with 10 previous lumbar surgeries

CB: 13 cm to the left
T10-L3: 61° → 38°
SVA: +33 cm
T10-L3: 73°
kyphosis → 32°

Flexibility
S/P T2-Pelvis with PCOs through the TL junction and L5-S1 ALIF

CB: 13 cm to the left
T10-L3: 61°
SVA: +33 cm
T10-L3: 73°
kyphosis
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)
  - **Aboliparitide**
    - 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.


Bone Quality (What can we do about it)

- **Anabolic agents**
  - **Teriparatide**
    - fully active (1-34) amino acid sequence of human parathyroid hormone (PTH)
  - **Aboliparitide**
    - 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

Bone Quality (What can we do about it)

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

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

Distal failure because of poor bone quality → 3CO

74 yo male
Rapidly progressive myelopathy
Extensive cardiac history
**Osteoporotic**

SVA: 15 cm
PI: 51°
LL: 17°
PT: 32°
T11-L3: 38° kyphosis

T8-L4 posterior fusion, T10-11 costotransversectomy and discectomy, L1-2 PCO, T11-12 PCO
Distal failure because of poor bone quality → 3CO

74 yo male
Rapidly progressive myelopathy
Extensive cardiac history
Osteoporotic

SVA: 15 cm → 7.5
PI: 51°
LL: 17° → 33°
PT: 32° → 23°
T11-L3: 38° → 5°

T8-L4 posterior fusion,
T10-11 costotransversectomy
and disectomy,
L1-2 PCO, T11-12 PCO

Distal failure because of poor bone quality → 3CO

2 months L4 PSO
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

Deformity Angular Ratio
Two Very Different 80 Degree Curves

Deformity Angular Ratio = 27

VCR
Deformity Angular Ratio = 16

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

- 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

Spinal Shape

• 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?

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

### Table: Age Adjusted Normative Sagittal Alignment Values

<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>11.1</td>
<td>−11.3</td>
<td>29.2</td>
<td>−29.1</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>35–44</td>
<td>8.8</td>
<td>40.7</td>
<td>11.77</td>
<td>−6.2</td>
<td>21.9</td>
<td>−4.0</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>45–54</td>
<td>19.9</td>
<td>51.2</td>
<td>15.43</td>
<td>−1.7</td>
<td>16.4</td>
<td>16.5</td>
<td>14.5</td>
<td></td>
</tr>
<tr>
<td>55–64</td>
<td>28.0</td>
<td>60.5</td>
<td>20.87</td>
<td>3.3</td>
<td>11.1</td>
<td>37.0</td>
<td>18.8</td>
<td></td>
</tr>
<tr>
<td>65–74</td>
<td>19.5</td>
<td>69.7</td>
<td>24.62</td>
<td>7.5</td>
<td>6.1</td>
<td>55.6</td>
<td>22.8</td>
<td></td>
</tr>
<tr>
<td>&gt;74</td>
<td>6.2</td>
<td>79.6</td>
<td>32.54</td>
<td>13.7</td>
<td>0.2</td>
<td>79.9</td>
<td>27.8</td>
<td></td>
</tr>
</tbody>
</table>

*Value extrapolated using the PCS US-norm.

---

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!
Avoiding Complications in Neuromuscular Scoliosis

Amer Samdani, MD
Chief of Surgery
Shriners Hospitals for Children
Philadelphia, PA

Disclosures: Amer F. Samdani, MD

- Consultant: DePuy Synthes Spine, Ethicon, Globus Medical, Medical Device Business Systems, Mirus, NuVasive, Orthofix, Stryker, Zimmer Biomet
- Royalties: NuVasive, Zimmer Biomet (I receive royalties on the The Tether from ZB)
- Setting Scoliosis Straight Foundation: Board and Executive Committee
- Pediatric Spine Study Group: Executive Committee
Reoperations in AIS

- Approx. 2% at 2 years, 5% at 5 years, 0% at 10 years
- Reasons
  - 50% infection
  - 50% implant related, adding on, thoracoplasty

Samdani et al, Spine 2013
Bartley et al, JBJS-A 2017
Mignemi et al, Spine Deform 2018

Getting Opinions (Not Just at Own Institution)

- Difficult cases (but sometimes the ‘easy’ ones are the most challenging)
- Intraoperative
  - Ego aside, most partners flattered
- Email, national conferences, partners
- Doc Matters, VuMedi, etc.
Effect of Preoperative Indications Conference on Procedural Planning for Treatment of Scoliosis

2020: Weekly Multidisciplinary Conference

Neuromuscular Scoliosis: Classification

Primary neuropathies
- Upper motor neuron
  - Cerebral palsy
  - Charcot-Marie-Tooth
  - Syringomyelia
  - Spinal cord tumor
  - Spinal cord trauma

- Lower motor neuron
  - Poliomyelitis
  - Traumatic
  - SMA
  - Werdnig-Hoffmann
  - Riley-Day syndrome

Primary myopathies
- Muscular dystrophy
- Duchenne’s muscular dystrophy
- Limb-girdle dystrophy
- Facioscapulohumeral dystrophy
- Arthrogryposis
- Fiber-type disproportion
- Congenital hypotonia
- Myotonia dystrophica

Combined upper/lower
Myelomeningocele
Complication Rates and Reasons

- Neuromuscular scoliosis carries a high complication rate (17-64%)
  - Shaffrey et al, Spine 2011
  - Thompson et al, Spine 2010
- Studies limited
  - Retrospective
  - Limited numbers and heterogeneous cohorts

Table 1. Classification of Major and Minor Complications*

<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory(s)</th>
<th>Major</th>
<th>Minor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory</td>
<td>Respiratory depression</td>
<td>Systolic blood pressure &lt;90 mm Hg with multiple transfusions, prolonged (&gt;24 h) intensive care unit monitoring, and/or vasoconstrictor support required</td>
<td>Resolution with increased fraction of inspired oxygen alone</td>
</tr>
<tr>
<td></td>
<td>Aspiration pneumonia, pneumonia, or aspiration pneumonia, pneumonia, or aspiration pneumonia</td>
<td>Neutropenia, prolonged (&gt;48 h) positive pressure ventilator support, or prolonged (&gt;24 h) intensive care unit monitoring required</td>
<td>Resolution with increased fraction of inspired oxygen and/or medical management</td>
</tr>
<tr>
<td></td>
<td>Pneumothorax or pneumotheorax, or chylothorax</td>
<td>Pneumothorax, prolonged (&gt;48 h) positive pressure ventilator support, or prolonged (&gt;24 h) intensive care unit monitoring required</td>
<td>Asymptomatic</td>
</tr>
<tr>
<td></td>
<td>Plural effusion</td>
<td>Plural effusion, prolonged (&gt;48 h) positive pressure ventilator support, or prolonged (&gt;24 h) intensive care unit monitoring required</td>
<td>Symptomatic and requiring invasive drainage</td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>Respiratory arrest</td>
<td>Respiratory arrest, prolonged (&gt;48 h) positive pressure ventilator support, or prolonged (&gt;24 h) intensive care unit monitoring required</td>
<td>Symptomatic and requiring invasive drainage</td>
</tr>
<tr>
<td></td>
<td>Constipation</td>
<td>Constipation</td>
<td>All classified as major</td>
</tr>
<tr>
<td></td>
<td>Superior mesenteric artery (SMA)</td>
<td>All classified as major</td>
<td>All classified as minor</td>
</tr>
<tr>
<td></td>
<td>Syndrome, pectoralis, or phlegmon</td>
<td>All classified as major</td>
<td>All classified as minor</td>
</tr>
<tr>
<td></td>
<td>Chlordakidic colitis or viral infections</td>
<td>All classified as major</td>
<td>All classified as minor</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>Heterodynamic instability</td>
<td>Heterodynamic instability</td>
<td>All classified as minor</td>
</tr>
<tr>
<td></td>
<td>Systolic blood pressure &lt;90 mm Hg</td>
<td>Systolic blood pressure &lt;90 mm Hg with multiple transfusions, prolonged (&gt;24 h) intensive care unit monitoring, and/or vasoconstrictor support required</td>
<td>Tachycardia or bradycardia and/or decreased urine output (&lt;1 mL/kg/h) with maintenance of systolic blood pressure &gt;60 mm Hg</td>
</tr>
<tr>
<td>Neurologic</td>
<td>Decreased motor function</td>
<td>Decreased motor function</td>
<td>Temporary deficit</td>
</tr>
<tr>
<td></td>
<td>Dural injury</td>
<td>Dural injury</td>
<td>Resolution with medical management</td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>Urinary retention</td>
<td>Urinary retention</td>
<td>Total nephrectomy</td>
</tr>
<tr>
<td></td>
<td>Chronic, requiring long-term catheterization</td>
<td>Chronic, requiring long-term catheterization</td>
<td>Temporary</td>
</tr>
<tr>
<td>Wound</td>
<td>All subcategories</td>
<td>All subcategories</td>
<td>All classified as minor</td>
</tr>
<tr>
<td></td>
<td>Reperfusion required</td>
<td>All subcategories</td>
<td>All classified as minor</td>
</tr>
<tr>
<td>Infeciton failure</td>
<td>All subcategories</td>
<td>All subcategories</td>
<td>All classified as minor</td>
</tr>
<tr>
<td>Progression</td>
<td>All subcategories</td>
<td>All subcategories</td>
<td>All classified as minor</td>
</tr>
</tbody>
</table>
Neuromuscular Scoliosis Complication Rates are Significantly Decreased from a Decade Ago: A Report from the SRS M&M Database

SW Hwang, AF Samdani, HM Keeny, DS Hanson, KM Blanke, JM Pahys

IMAST South Africa 2017

<table>
<thead>
<tr>
<th>Year</th>
<th>Complication Rate</th>
<th>Wound Infection Rate</th>
<th>Superficial Wound Infection</th>
<th>Deep Wound Infection</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>15%</td>
<td>6.0%</td>
<td>1.9%</td>
<td>4.1%</td>
</tr>
<tr>
<td>2005</td>
<td>16%</td>
<td>5.9%</td>
<td>1.8%</td>
<td>4.1%</td>
</tr>
<tr>
<td>2006</td>
<td>15%</td>
<td>5.8%</td>
<td>1.9%</td>
<td>3.9%</td>
</tr>
<tr>
<td>2007</td>
<td>13%</td>
<td>5.3%</td>
<td>1.8%</td>
<td>3.5%</td>
</tr>
<tr>
<td>2008</td>
<td>11%</td>
<td>5.3%</td>
<td>1.8%</td>
<td>3.5%</td>
</tr>
<tr>
<td>2009</td>
<td>3.4%</td>
<td>5.3%</td>
<td>1.8%</td>
<td>3.5%</td>
</tr>
<tr>
<td>2010</td>
<td>1.1%</td>
<td>5.3%</td>
<td>1.8%</td>
<td>3.5%</td>
</tr>
<tr>
<td>2011</td>
<td>0.9%</td>
<td>2.7%</td>
<td>0.59%</td>
<td>2.0%</td>
</tr>
<tr>
<td>2012</td>
<td>3.5%</td>
<td>3.3%</td>
<td>1.0%</td>
<td>2.1%</td>
</tr>
<tr>
<td>2013</td>
<td>4.2%</td>
<td>3.2%</td>
<td>0.65%</td>
<td>2.3%</td>
</tr>
<tr>
<td>2014</td>
<td>4.2%</td>
<td>3.5%</td>
<td>0.55%</td>
<td>2.7%</td>
</tr>
<tr>
<td>2015</td>
<td>4.4%</td>
<td>3.5%</td>
<td>0.55%</td>
<td>2.7%</td>
</tr>
</tbody>
</table>
Major Perioperative Complications after Spine Surgery in Patients with Cerebral Palsy: Assessment of Risk Factors

<table>
<thead>
<tr>
<th>Patients (N)</th>
<th>127</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age ± Standard Deviation [SD] (years)</td>
<td>14.3 ± 2.6</td>
</tr>
<tr>
<td>Males (%)</td>
<td>58.3</td>
</tr>
<tr>
<td>Approach</td>
<td></td>
</tr>
<tr>
<td>Posterior</td>
<td>112</td>
</tr>
<tr>
<td>Anterior/posterior</td>
<td>14</td>
</tr>
<tr>
<td>Anterior</td>
<td>1</td>
</tr>
<tr>
<td>Coronal Cobb angle</td>
<td></td>
</tr>
<tr>
<td>Major ± SD (°)</td>
<td>80.9 ± 27.4</td>
</tr>
<tr>
<td>Minor ± SD (°)</td>
<td>35.6 ± 16.8</td>
</tr>
<tr>
<td>% Flexibility</td>
<td></td>
</tr>
<tr>
<td>Major ± SD (%)</td>
<td>36.0 ± 16.9</td>
</tr>
<tr>
<td>Minor ± SD (%)</td>
<td>29.1 ± 22.5</td>
</tr>
<tr>
<td>Kyphosis (T2-T12) ± SD (°)</td>
<td>43.1 ± 23.1</td>
</tr>
<tr>
<td>Lordosis (T12 to top of sacrum) ± SD (°)</td>
<td>-38.4 ± 33.6</td>
</tr>
<tr>
<td>Sagittal balance (C7 to sacrum) ± SD (cm)</td>
<td>1.6 ± 6.9</td>
</tr>
<tr>
<td>Pelvic obliquity ± SD (°)</td>
<td>63.1 ± 14.9</td>
</tr>
</tbody>
</table>
Distribution of Major Perioperative Complications

<table>
<thead>
<tr>
<th>Complication</th>
<th>Yes (n=50)</th>
<th>No (n=77)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Complications (%)</td>
<td>39.4</td>
<td></td>
</tr>
<tr>
<td>Pulmonary (%)</td>
<td>29.9</td>
<td></td>
</tr>
<tr>
<td>Gastrointestinal (%)</td>
<td>18.9</td>
<td></td>
</tr>
<tr>
<td>Other medical (%)</td>
<td>11.8</td>
<td></td>
</tr>
<tr>
<td>Wound infection (%)</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>Instrumentation related (%)</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Unplanned staged surgery (%)</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Neurologic (%)</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

Risk Factors

<table>
<thead>
<tr>
<th>Complication</th>
<th>Yes (n=50)</th>
<th>No (n=77)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBL (mL) P&lt;0.001</td>
<td>2843 ± 1732</td>
<td>1656 ± 1150</td>
</tr>
<tr>
<td>Kyphosis (º) P=0.05</td>
<td>48 ± 21</td>
<td>40 ± 23</td>
</tr>
<tr>
<td>Staged procedure P=0.02</td>
<td>73%</td>
<td>27%</td>
</tr>
<tr>
<td>Antifibrin P=0.05</td>
<td>30%</td>
<td>70%</td>
</tr>
<tr>
<td>Nutrition P&lt;0.001</td>
<td>55%</td>
<td>45%</td>
</tr>
<tr>
<td>BMI P=0.08</td>
<td>17.8 ± 5.5</td>
<td>20.9 ± 9.9</td>
</tr>
</tbody>
</table>
Neurologic

- IONM
  - Mo et al, JPO 2017
    - No signals in 31%
    - Hydrocephalus a predictor
- Does it matter?
  - Bowel bladder
  - Spasticity
- Pre-op discussion imperative

Incidence of and Risk Factors for Loss of 1 Blood Volume During Spinal Fusion Surgery in Patients with CP
Jain et al, JPO 37:e484, 2017

- 272 patients
- 108 patients lost one blood volume
- Unit rods and higher magnitude Cobb increased risk
Antifibrinolytics

- Numerous studies document efficacy
  - Grant et al, JPO 2009
  - Thompson et al, Spine 2008
  - Dhawale et al, Spine 2012
- Dosing?
  - 50 mg/kg loading, followed by 5 mg/kg
    - Johnson et al, JPO 2017

Complications

- Medical
  - Evaluation by multidisciplinary team
    - Optimize nutrition
      - GI tube
      - NG feeds
    - Aggressive mobilization
  - Reoperations
Reoperations in Patients With CP

- 251 patients with minimum 2 year follow-up
- Total reoperations:
  - 37 reoperations in 35 patients (13.9%)
    - Infection: 20 (54.1%)
    - Instrumentation related: 17 (45.9%)
      - Loosening (5)
      - Prominence (5)
      - Broken (4)
      - Junctional kyphosis (3)

Deep Wound Infections After Spinal Fusion in Children with CP
Sponseller et al, Spine Def 38:2013

- Wound infection after spine fusion for CP more common than for other diagnoses
- 204 patients with CP studied to identify factors that were significantly associated with development of infection
- Deep wound infection developed in 13 children (6.4%)
- Mean time to infection was 34.2 ± 60.2 days
Sponseller et al, cont.

- Significantly associated with infection: Older age, larger curve size, presence of gastrostomy/gastrojejunostomy tube, higher pre-op serum WBC count, longer operative time

- Organisms:
  - E. coli (5 patients)
  - Pseudomonas aeruginosa (2)
  - Methicillin-susceptible S. aureus (1)
  - Proteus mirabilis (1)
  - Polymicrobial organisms (4)

- Conclusions: surgeons may want to consider gram-negative antibiotic prophylaxis.

Building Consensus: Development of a Best Practice Guideline (BPG) for Surgical Site Infection (SSI) Prevention in High-risk Pediatric Spine Surgery

Vitale M JPO 2013
Avoiding Infection

- Pre-op coverage with gram positive and gram negative
- Intra-op wound antibiotics
  - Gram negative and positive coverage
- Post-op
  - Strict adherence to dressing
- Early infection can usually be managed with washout and long-term antibiotics but will recur.

Density of Implants

- Flexible curves likely amenable to lower density
  - SRS 2017 submission
    - 146 patients
    - LD and HD equivalent results
- How about L5-S1-ilial
  - Surface area for fusion
  - Fixation
Early Pelvic Fixation Failure in Neuromuscular Scoliosis
Myung, Lee, Skaggs JPO 35:258, 2015

- Purpose: to report on early failures of pelvic fixation in PSF for NM scoliosis
- 41 patients, mean age 14 years, mean 16 levels fused
- Diagnoses included CP (22), Duchenne MD (7), other NM (10), and spina bifida (2)
- Mean pre-op primary Cobb was 82° (range: 21 to 144°)

- Pelvic obliquity correction was 76%
- Pelvic fixation failed in 12/41 (29%)
- Mean time from surgery to failure was 18 months (1-49)
- Conclusion: Not placing bilateral pedicle screws at L5 and S1, in addition to 2 iliac screws, was associated with a 35% early failure rate of pelvic fixation
Patient K.L.

Interbody Fusion

- Usually L5-S1
- All ambulatory patients
- Consider for others depending on bone quality, fixation points, and activity
  - SCI versus cognitively impaired patient
Minimally Invasive Lateral Interbody Fusion in the Treatment of Scoliosis Associated with Myelomeningocele

- Purpose: to report MILIF to address the issue of fusion between vertebrae while minimizing the morbidity of an open approach
- 4 patients: MM, Cobb >70º, PSF using >80% pedicle screws, age >10 y, min 2y f/u

Proximal Junctional Kyphosis

- Hard to determine set point for specific child
- Try not to overcorrect
- Bend kyphosis proximally
- If have to extend superiorly
  - Consider ACDF to supplement if lateral mass fixation weak
Primary Kyphosis versus Primary Scoliosis in Surgical Patients with Cerebral Palsy: Complications and Reoperations Differ

- Prospective multicenter study of patients with CP undergoing spinal fusion
- 221 patients with at least 2-year follow-up
  - Primary kyphosis (PK) cohort: 18 patients
  - Primary scoliosis (PS) cohort: 203 patients
- Outcomes examined:
  - Reoperations, complications, radiographic measures, CPCHILD scores
  - Specific focus on implant-related complications

Reoperation

- Primary kyphosis 33% (6/18)
  - Implant related: 5
- Primary scoliosis 12% (24/203)
  - Implant related: 2

PK mean time to implant issue 374 ± 310 days
PS mean time to implant issue 753 ± 702 days
Avoiding Complications

- Preoperative optimization
  - Nutrition
- Infection
  - Antibiotics
  - Dressings
- Implant-related reoperations
  - Iliac screws
  - Proximal junctional kyphosis
- Don’t let deformity get too large

Larger Curve Magnitude Is Associated with Markedly Increased Perioperative Complications After Scoliosis Surgery in Patients with SCI

Amer F. Samdani MD, Patrick Cahill MD, Joseph King MD, Steven Hwang MD, Anthony Fine BA, Joseph Ferguson BA, Randal Betz MD

Shriners Hospitals for Children, Philadelphia, PA, USA

18th International Meeting on Advanced Spine Techniques
Copenhagen, Denmark
July 2011
**Results**

<table>
<thead>
<tr>
<th></th>
<th>Small Curves &lt;70°</th>
<th>Large Curves &gt;70°</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age (years)</td>
<td>12.5 ± 2</td>
<td>14.7 ± 2</td>
<td>0.001</td>
</tr>
<tr>
<td>Major curve</td>
<td>54 ± 12°</td>
<td>85 ± 11°</td>
<td>0.000</td>
</tr>
<tr>
<td>Operative time (minutes)</td>
<td>463 ± 87</td>
<td>536 ± 122</td>
<td>0.016</td>
</tr>
<tr>
<td>Blood loss (cc)</td>
<td>2673 ± 1437</td>
<td>3524 ± 2199</td>
<td>0.075</td>
</tr>
<tr>
<td>Mean hospital stay (days)</td>
<td>10.9 ± 4</td>
<td>14.9 ± 9</td>
<td>0.048</td>
</tr>
<tr>
<td>Major perioperative complication</td>
<td>21%</td>
<td>36%</td>
<td></td>
</tr>
</tbody>
</table>

**Complications**

- Small curves
  - 21% (4/19)
- Dural tear
- Pneumonia
- Prolonged intubation
- Wound infection
Complications

- Larger curves
  - 36% (9/26)
  - Wound infections (3)
  - Aspiration (2)
  - Prolonged intubation (2)
  - Dural tear
  - Unplanned staged surgery (excessive blood loss)
- Sepsis
- ARDS
- Vision loss

Conclusion

- Complications not uncommon in patients with NM scoliosis
- Preoperative multidisciplinary evaluation and discussion with family
- Reoperation rate close to 15% with half being for infection
OSTEOPOROSIS DEFINITION

- Systemic disease characterized by **low bone mass and microarchitectural deterioration of bone tissue**, with a consequent increase in bone fragility and susceptibility to fracture
- Diagnosed by either:
  - Low bone mineral density (BMD g/cm²) T-score of -2.5
  - History of fragility fracture
- Fragility fracture is frequently described as a fracture occurring as the result of minimal trauma or a fall from standing height or less
BONE STRENGTH

- BMD determines 60-80% of bone strength
  - DEXA is gold standard to assess skeletal mass
  - Bone mineral content per square centimeter
  - Used to diagnose osteoporosis, predict fracture risk and as a measure to quantitate response to medical treatment

- Microarchitecture of trabecular and cortical bone better studied by high-resolution peripheral quantitative CT
  - Not widely available

---

**Shifting the Osteoporosis Paradigm**

**Bone Strength**

NIH Consensus Statement 2000

Bone Strength = Bone Quality and Bone Mineral Density

- Microarchitecture
  - Geometry
  - Turnover Rate
  - Damage Accumulation
  - Degree of Mineralization
  - Properties of the Collagen/mineral Matrix

aBMD (areal) = g/cm²
vBMD (volumetric) = g/cm³

Source: NIH Consensus Development Panel on Osteoporosis, JAMA 285:785-95, 2001
PREVALENCE

- Most prevalent bone disease in the US
- Affects 10.2 million Americans (80% women)
- Prevalence of osteoporosis is increasing

![Projection of Number of People with Osteoporosis and Low Bone Mass at the Femoral Neck or Lumbar Spine, United States 2010 to 2030](image)

THE BURDEN

- 2 million osteoporotic fractures annually
- 500,000+ hospitalizations
- 800,000+ ER encounters
- 2.6 million + office visits
- 180,000 nursing home admissions
- Direct cost $17-22 billion for osteoporotic fractures
INCIDENCE

- 1 in 2 women and 1 in 4 men > age 50 will have an osteoporosis-related fracture in their lifetime
  - For women, fracture incidence per year exceeds stroke, MI and breast cancer combined
  - For men, fracture risk higher than prostate cancer

Eastell et al. QJM 2001; 94:575-59

OSTEOPOROSIS IN PERSPECTIVE

Americans with Risk Factors, in Millions

- Low Bone Mass +/- Osteoporosis: 53 M
- Uncontrolled HT: 36 M
- Uncontrolled LDL: 48 M
THE ROLE OF ORTHOPEDIC SURGEONS

- Orthopedic surgeons are often the first and may be only physician to see a fracture patient

- Multinational Survey of Osteoporotic Fracture Management
  *Dreinhöfer et al. Osteoporos Int 2005; 16:S44-S54*
  - Survey of 3422 orthopedic surgeons from 6 countries
  - 90% do not routinely measure bone density following first fracture
  - 75% are lacking appropriate knowledge about osteoporosis

- 133 spine surgeons
  - 44% routinely obtain DEXA scan before performing instrumented spinal fusion
  - <12% check metabolic labs (Ca, vit D and PTH)
  - 74% did so because it altered treatment plan and 53% would refer patient for osteoporosis management before spinal fusion
TREATMENT GAP

- Osteoporosis remains undertreated in patients who suffer fragility fractures
- Most patients (80%) with fragility fractures do not receive a follow-up test or osteoporosis medication

*AARP Public Policy Institute analysis of data from the OptumLabs Data Warehouse*

OSTEOPOROSIS MEDICATION USE

- Osteoporosis medication use decreased from 2002 to 2011

*Graph showing the percentage of patients initiating treatment within 1 year of fracture for both women and men.*
BONE REMODELING

- Bone remodeling is performed by basic multicellular unit (BMU) within bone remodeling cavity

PATHOGENESIS

- Bone loss begins in the 40s and rapid bone loss in women occurs 5-10 years after menopause
- Cellular and molecular changes occur after loss of estrogen (menopause)
UNBALANCED REMODELING

Resorption > Formation ➔ Net bone loss

- Inadequate Calcium or Vitamin D
- Menopause
- Aging
- Medications or Diseases

Osteoporosis

Normal Bone Structure

Osteoporotic Bone Structure

SECONDARY OSTEOPOROSIS

- Nutritional
  - Malabsorption
  - Malnutrition
- Inflammatory Disorders
  - Rheumatoid arthritis
  - Ankylosing spondylitis
- Endocrine Disorders
  - Gonadal insufficiency
  - Hyperparathyroidism
  - Thyroid disease
- Drug-Induced
  - Corticosteroids
  - Alcohol
  - Anticonvulsants
- Malignant Disease
  - Carcinomatosis
  - Multiple myeloma, Leukemia
- Other
  - Smoking
  - Chronic renal disease
BIOLOGY OF SPINAL FUSION

- Primary vascular supply to fusion mass originates from decorticated bone
- Intra-membranous bone formation
- Endochondral bone formation
  - Poor vascular supply and low oxygen saturation in central zone

SPINE SURGERY IN THE ELDERLY

- Increasing trend to perform spinal surgery in the elderly
  

- Osteoporosis increasing in patients undergoing spine surgery
  
  - 1300 patients
    - 51% in females
    - 15% in males
  
STRATEGIES TO PROMOTE FUSION

- BMD inversely correlated with pedicle screw strength
  - Surgical and technical considerations
- Negative bone remodeling can cause delayed bone fusion
  - Nonunion negatively impacts clinical outcomes
  - Old age and osteoporosis are not contraindications in spinal fusion
  - Systemic or pharmacotherapeutic strategies to facilitate positive bone remodeling

FDA-APPROVED THERAPEUTIC OPTIONS

<table>
<thead>
<tr>
<th>Prevention</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stops Bone Loss</strong></td>
<td><strong>Reduces Fragility Fractures</strong></td>
</tr>
<tr>
<td>Estrogen</td>
<td>Calcitonin</td>
</tr>
<tr>
<td>Alendronate</td>
<td>PTH (Teriparatide)</td>
</tr>
<tr>
<td>Risedronate</td>
<td>Denosumab</td>
</tr>
<tr>
<td>Ibandronate</td>
<td>Abaloparatide</td>
</tr>
<tr>
<td>Zoledronic acid</td>
<td></td>
</tr>
</tbody>
</table>
**ANTIRESORPTIVE VS ANABOLIC**

- **Antiresorptive**
  - Decrease bone resorption → Decrease in formation “BMD” tends to plateau after several years
  - Most treatment agents
  - Bisphosphonates, SERMs, calcitonin, estrogen, denosumab

- **Anabolic**
  - Stimulate bone formation
  - Teriparatide
  - Abaloparatide

- *Are spinal fusions affected by systemic treatments?*

**BISPHOPHONATES**

- Medications: Alendronate, Risendronate, Zolendronic acid, Ibandronate
- Suppress resorption by preventing osteoclast attachment to bone matrix
- Improves BMD, reduces vertebral and non-vertebral fracture risk by 40-70%
- **Lower fusion rate** 50% in alendronate-treated animals vs 95% in control
- Fusion masses in alendronate-treated animals radiographically larger and denser
- Alendronate inhibits bone graft resorption and incorporation by quantitative histomorphometry

- **Improved osteogenesis** and biomechanical strength of fusion mass in osteoporotic animal model
• 40 osteoporotic patients undergoing single level PLIF
• Alendronate vs Vitamin D
• **Higher fusion rate** in Alendronate group (95% vs 65%)

• 94 patients
• Fusion rate in ZA group
  - 90% at 6 months (vs 75%)
  - 92% at 12 months (vs 92.86%)
  - Reduced adjacent vertebral compression fracture rate (0 vs 5)
  - Reduced pedicle screw loosening (0 vs 6)
**No difference** in fusion rate or mass between autograft or allograft + ZAL (single dose)

Zoledronic acid infusion for lumbar interbody fusion in osteoporosis


- 75% fusion in ZOL vs 56% control at 2 years
  - Reduced vertebral compression fracture rate (19% vs 56%)
  - Reduced pedicle screw loosening (18% vs 45%)
  - Less cage subsidence (28% vs 54%)

**Mixed data regarding effect of bisphosphonates on fusion rate**

- Anti-fracture effect not proportional to efficacy on bone fusion
- May inhibit or delay bone fusion by uncoupling balanced osteoclastic and osteoblastic activity inherent to bone healing
- Dependent on methodology to define fusion
  - No significant difference by manual palpation and/or radiographic evaluation
- Decreased fusion rate using histologic definition
  - More immature/unremodeled bone, more cartilage and reduced osteoclast and osteoblast activity
DENOSUMAB (PROLIA)

- Monoclonal antibody to RANK Ligand
- Prevents formation of active osteoclasts
  - Inhibits bone resorption
- Shorter biologic half-life than bisphosphonates
- Reduces fracture risk
  - Vertebral: 68%
  - Hip: 40%
- Effect on spinal fusion needs be evaluated

TERIPARATIDE

- N-terminal peptide of PTH
- Stimulates osteoblast activity and overall bone remodeling resulting in new bone formation
- Moderate to severe osteoporosis
- Improves trabecular microarchitecture
- Increases cortical thickness
- Reduces fracture risk
  - Vertebral: 65%
  - Non-vertebral: 53%
Intermittent PTH administration accelerates bone modeling predominantly by stimulating bone formation at fusion mass resulting in **increased fusion rate** (89% vs 56%).

Also **improves bone microarchitecture** of trabecular bone sites including vertebral body and distal femur metaphysis, modest effects on cortical bone.

- 57 patients undergoing 1- and 2-level PLIF
- PTH vs Risedronate 2 months before and 8 months after surgery
- Shorter time to union in PTH group (8.5 vs 9.9 months)
- Higher rate of fusion in PTH group (84% vs 82% by CT, 74% vs 68% by radiographs)
Comparison of Teriparatide and Bisphosphonate Treatment to Reduce Pedicle Screw Loosening After Lumbar Spinal Fusion Surgery in Postmenopausal Women With Osteoporosis From a Bone Quality Perspective

<table>
<thead>
<tr>
<th>TABLE 2. Number of Fusion Level and Evaluation of PS Loosening</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>No. of patients</td>
</tr>
<tr>
<td>No. of fusion level</td>
</tr>
<tr>
<td>No. of patients showing loosening of PS (%)</td>
</tr>
<tr>
<td>No. of loosening of PS (%)</td>
</tr>
<tr>
<td>Evaluation by radiography</td>
</tr>
<tr>
<td>Evaluation by CT</td>
</tr>
<tr>
<td>Total no. of evaluated PS</td>
</tr>
</tbody>
</table>

P < 0.05 was considered statistically significant. * and ** denote data for statistical analysis.

Observational Study

Retrospective radiological outcome analysis following teriparatide use in elderly patients undergoing multilevel instrumented lumbar fusion surgery

Table 2

<table>
<thead>
<tr>
<th>Results</th>
<th>Teriparatide group</th>
<th>Control group</th>
<th>Statistical analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fusion, 1 y. — evaluation by radiography</td>
<td>No. of patients</td>
<td>No. of patients</td>
<td>P=0.20</td>
</tr>
<tr>
<td>Solid fusion</td>
<td>20 (86.7%)</td>
<td>16 (60%)</td>
<td></td>
</tr>
<tr>
<td>Nonunion</td>
<td>10 (33.3%)</td>
<td>16 (60%)</td>
<td></td>
</tr>
<tr>
<td>Screw loosening—evaluation by radiography</td>
<td>No. of screws</td>
<td>No. of screws</td>
<td>P=0.001</td>
</tr>
<tr>
<td>1 y</td>
<td>36 (13.3%)</td>
<td>69 (24.4%)</td>
<td></td>
</tr>
</tbody>
</table>

Values are presented as total number percentages. A probability value (P < 0.05) was considered statistically significant.
- 58 patients with osteoporosis undergoing long fusions (>9 levels) with or without 3-column osteotomy

| Table 1  Summary of adult spinal deformity in female patients with osteoporosis |
|-----------------|-----------------|--------|
|                  | Biophosphonate treatment group | P value |
| No. patients     | 25               | 35     |
| Age (years)      | 73.5 ± 2 (68-2)  | 72.5 ± 5 (68-81) | NS |
| ≥75 years of age | 11               | 15     | NS |
| <75 years of age | 14               | 12     | NS |
| BMD (T-score)    | 0.667 ± 0.118 g/cm² (-3.8 ± 0.3) | 0.652 ± 0.128 g/cm² (-3.9 ± 0.3) | NS |
| BMD (T-score) 75 and over | 0.656 ± 0.118 g/cm² (-3.9 ± 0.2) | 0.656 ± 0.118 g/cm² (-4.1 ± 0.2) | NS |
| BMD (T-score) under 75 | 0.677 ± 0.118 g/cm² (-3.7 ± 0.2) | 0.687 ± 0.158 g/cm² (-3.8 ± 0.2) | NS |
| Diabetes mellitus | 4                | 4      | NS |
| Department of spinal motion (kyphotic angle, main location of the fusion, number of vertebral fractures) | 19 (50°-7, T-5, L-10, L-5, 3) | 23 (50°-9, T-11, T-12, L-5, L-10) | NS |
| Coronal curve type | 7                | 10     | NS |
| Average fusion level | 9.9 ± 3.9        | 9.9 ± 2.2 | NS |
| Treatment with VCR or PND | 10               | 14     | NS |
| Treatment with TLP | 23               | 22     | NS |

- **PTH group**
  - Higher rate of facet fusion and total fusion (89% vs 77%)
  - Less adjacent vertebral compression fractures (48% vs 12%)
  - Reduced rates of instrumentation failure (screw loosening, rod breakage)
  - Improved clinical outcomes (pain scores and ODI)
    - Differences were considered due to difference between spinal fusion rates and complications related to adjacent vertebral fractures
- 75 patients undergoing PLIF or TLIF
- Higher fusion rate (69% vs 35%) at 6 months
- Decreased bone resorption
  - Increased P1NP/CTX and decreased TRACP-5p

- 45 patients undergoing 1 or 2 level PLF
- Improved fusion rate and time to fusion in long-duration treatment group
  - 92% at 7.5 months (long)
  - 80% at 8.5 months (short)
  - 70% at 10 months (bisphonate)
TERIPARATIDE

- Dose-dependent enhancement of spinal fusion rates in animal studies
  - Histologically more mature fusion mass with greater proportion of mineralized tissue and more robust microstructure
- Daily PTH administration results in more rapid bone fusion following PLIF compared to oral bisphosphonate administration in prospective studies

ON THE HORIZON

- Abaloparatide (Tymlos)
  - PTH analog, PTH1 receptor agonist
  - Fracture reduction
    - 86% vertebral fractures
    - 43% non-vertebral fractures
  - Effect on spinal fusion needs to be evaluated
ON THE HORIZON

- **Anti-sclerostin antibody (Romosozumab)**
  - Glycoprotein secreted by osteocytes, inhibits anabolic Wnt signaling pathway, increases RANK-L
  - Monoclonal antibody to sclerostin induces osteoblast activity and new bone formation
  - Restores bone mass and bone architecture in animal studies
    - Ominsky M et al. J Bone Miner Res. 20016;21(Supp 1):S44
  - **Cathepsin K Inhibitor – Odanacatib**

SURGICAL CONSIDERATIONS

- **Techniques to enhance pullout strength of pedicle screws**
  - Bigger, longer pedicle screws
  - Screw hole preparation (undertapping or no tapping)
  - Angulation and screw positioning
  - Cement augmentation of pedicle screws
SURGICAL CONSIDERATIONS

- Multiple points of fixation
- Multiple osteotomies
- Accept lesser degrees of deformity correction
- Anterior column support L5-S1 and/or iliac fixation
- Avoid ending instrumentation within kyphotic segment

SUMMARY

- Osteoporosis is common
- Need for high quality studies
- Treat osteoporosis early and aggressively!
Optimization of Implant Density and Distribution for AIS Correction

J. Matthew Cage, DO
Assistant Professor of Surgery
F. Hebert School of Medicine
Uniformed Services University of Health Sciences
Department of Orthopaedic Surgery
Tripler Army Medical Center

Disclaimer

I have no financial disclosures to report

The opinions or assertions contained herein are the private views of the author(s) and are not to be construed as official or as reflecting the views of the Department of Defense
The Cost of AIS

Hospital Cost Analysis of Adolescent Idiopathic Scoliosis Correction Surgery in 125 Consecutive Cases

By Jonathan R. Kasner, MD, Martin Quiros, MD, Joshua D. Auerbach, MD, Andrew H. Milby, BS, Lynne Wintzke, BS, Laura Dean, BA, Joseph W. Dryer, MD, Thomas J. Erizzo, MD, and Barra S. Loner, MD

Conclusions: The largest contributors to overall cost were implants (29%), intensive care unit and inpatient room costs (22%), operating room time (9.9%), and bone grafts (6%). There were three significant independent predictors of increased total cost: the surgical approach used, the number of pedicle screws placed, and the number of vertebral levels fused. This study characterizes the relative contributions of factors that contribute to total costs, charges, and reim-

8/2/2021
The Cost of AIS

**Spine Deformity**

Increasing Hospital Charges for Adolescent Idiopathic Scoliosis in the United States

Christopher T. Martin, MD, Andrew I. Pogho, MD, Yehya Gom, PhD, Sergio A. Montesano-Lattes, MD, Ruan M. Hjortland, MD, John E. Callaghan, MD, and Stuart I. Weinstein, MD

![Graph showing increasing hospital charges for AIS](image)

Growing Concerns

**AIS SUPPLEMENT**

"Does the Outcome of Adolescent Idiopathic Scoliosis Surgery Justify the Rising Cost of the Procedures?"

James W. Roach, MD,* Charles T. Mehlman, DO, MPH,* and James O. Sanders, MD,*
Safety

- Pedicle screw malposition
  - 9% (Ledonio et al JBJS 2011, SRS and POSNA task force)

- Revision surgery for screw malposition
  - 0.8-4.3% (Larson et al JNS 2016, Minimize Implants Maximize Outcomes Study Group)
Safety

- Lower implant density
  - Decreased blood loss (Kemppainen et al, Spine Deformity 2016)
  - Decreased operative time (Kemppainen et al, Spine Deformity 2016)
  - Increased surface area for fusion
  - Decreased radiation exposure (find radiation article)

The big question

- Can we produce equivalent or better clinical results with less pedicle screws?
The Evolution of Increased Implant Density

- Better coronal plane correction
- Better maintenance of correction
- Better correction of the compensatory curve
The Evolution of Increased Implant Density

- Thoracic Adolescent Idiopathic Scoliosis Curves Between 70° and 100°: Is Anterior Release Necessary?
- Operative Treatment of Adolescent Idiopathic Scoliosis With Posterior Pedicle Screw-Only Constructs: Minimum Three-Year Follow-up of One Hundred Hundred Cases
- The Treatment of Large (>70°) Thoracic Idiopathic Scoliosis Curves With Posterior Instrumentation and Arthrodesis: When is Anterior Release Indicated?
- Selective Posterior Thoracic Fusions for Adolescent Idiopathic Scoliosis: Comparison of Hooks Versus Pedicle Screws
- Comparative Analysis of Pedicle Screw Versus Hook Instrumentation in Posterior Spinal Fusion of Adolescent Idiopathic Scoliosis

The evolution of implant density

- Implant Density
- Coronal-Cobb Angle Correction

- Graph: Trend for increasing implant density in scoliosis corpectomy surgery per year without change in magnitude of surgical Cobb angle correction
The evolution of implant density

- Rod rotation
- Cantilever deformity correction
- In situ rod contouring
- Direct vertebral rotation
- En Bloc vertebral rotation
- Differential Rod bending

The concept of “implant density”

- Implant density = # fixation points/# levels fused
- Maximum implant density = 2.0
The concept of “implant density”

Clements et al, Spine 2009

• Greater implant density was associated with greater major curve correction
• Hooks and screws were included
• Increased implant density was associated with decreased thoracic kyphosis

Li et al, J Spinal Disorders and Techniques

1st RCT

No difference between skipped versus continuous pedicle screw placement on the concave ("correcting") rod
Radiographic Results – Coronal Plane

- Implant Density 1.04-2.0 screws per level
- Coronal Correction 64%-70%

Radiographic Results – Coronal Plane

- Lenke 1 curves: HD 69% vs LD 66%, p = 0.0022
- Lenke 2 curves: HD 68% vs LD 63%, p = 0.0073
Radiographic Results – Coronal Plane

The effect of cortical bone density in thoracic adolescent idiopathic scoliosis

Radiographic Results – Sagittal Plane

Correction of Main Thoracic Adolescent Idiopathic Scoliosis Using Pedicle Screw Instrumentation

Does Higher Implant Density Improve Correction?

Correction of Scoliosis Curve Correction With the Number and Type of Fixation Anchors

J. Matthew Cage, DO, MAJ, MC, USA

UNCLASSIFIED

TRIPLER ARMY MEDICAL CENTER
Radiographic Results – Sagittal Plane

• Surgeon was the only significant predictor of restoration of normal kyphosis

fulcrum. The vertebral bodies and the intervertebral discs contribute to the anterior lengthening, but the intervertebral discs contribute four times more. The posterior shortening appeared to be caused by compression of the interlaminar space not by an active growth disturbance of the bony laminae.

Brink et al, The Spine Journal, 2018

Radiographic Results – Axial plane

<table>
<thead>
<tr>
<th>TABLE 1: Demographic and Clinical Features of the Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Sex (male/female)</td>
</tr>
<tr>
<td>Preoperative normal Cobb angle (°)</td>
</tr>
<tr>
<td>Preoperative coronal Cobb angle (°)</td>
</tr>
<tr>
<td>Preoperative D-12 lumbar angle (°)</td>
</tr>
<tr>
<td>Postoperative T1-12 lumbar angle (°)</td>
</tr>
<tr>
<td>Scoliosis AHR (%)</td>
</tr>
<tr>
<td>Fusion level 1</td>
</tr>
<tr>
<td>Number of fusion levels</td>
</tr>
<tr>
<td>Implant density</td>
</tr>
</tbody>
</table>

*For each of the variables, the effect size was calculated using the mean, standard deviation, and mean difference. The effect size was calculated using the formula: effect size = (mean difference) / (pooled standard deviation).
Radiographic Results – Axial Plane

ATR = angle of trunk rotation

Implant Density vs Distribution

J. Matthew Cage, DO, MAJ, MC, USA

UNCLASSIFIED
TRIPLER ARMY MEDICAL CENTER
Implant Density vs Distribution

- Concave implant density correlation with curve correction $R = 0.17$, $P = 0.003$
- Convex implant density did NOT correlate with curve correction $P = 0.8$
- Concave apical region implant density correlation with curve correction $R = 0.19$, $P = 0.002$

Radiographic Results - Summary

- **Intrinsic**
  - Curve magnitude, location, type
  - Curve flexibility
  - Elastic recoil of the ribs and spine
- **Extrinsic**
  - Performance of releases
  - Rod material and size
  - Screw size and type
  - Correction maneuvers
  - Rod contouring
  - Fusion length
Biomechanical Results

Implant Density at the Apex is More Important Than Overall Implant Density for 3D Correction in Thoracic Adolescent Idiopathic Scoliosis Using Rod Derotation and En Bloc Vertebral Derotation Technique

Coronal Plane

Average postoperative MT Cobb angle (°)

Average postoperative T4-T12 Thoracic Kyphosis (°)

Dellikaris et al, Spine 2018
Rotational Correction

Screw/Bone Interface Stress

Delikaris et al, Spine 2018
Biomechanical Results

- Coronal curve correction equivalent with high and low implant densities
- UA screw > multi-axial and favored angle screws
Clinical results

**SPINE**

Implant density is not related to patient-reported outcome in the surgical treatment of patients with idiopathic scoliosis

Table I. Patient-reported data at one-year and mean 3.1-year follow-up.

<table>
<thead>
<tr>
<th>One-year following</th>
<th>Mean ± SD</th>
<th>Mean ± SD</th>
<th>Mean ± SD</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low implant</td>
<td>1.91</td>
<td>1.65</td>
<td>1.36</td>
<td></td>
</tr>
<tr>
<td>High implant</td>
<td>2.34</td>
<td>2.20</td>
<td>2.26</td>
<td></td>
</tr>
<tr>
<td>Clinical results</td>
<td>4.6 (2.98)</td>
<td>4.1 (2.87)</td>
<td>4.2 (2.95)</td>
<td>4.8 (3.06)</td>
</tr>
<tr>
<td>FDA 30 score</td>
<td>90.7 (11.3)</td>
<td>80.8 (11.3)</td>
<td>90.5 (11.3)</td>
<td>100 (11.3)</td>
</tr>
<tr>
<td>SAQ appearance</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>SAQ satisfaction</td>
<td>100 (1)</td>
<td>100 (1)</td>
<td>100 (1)</td>
<td>100 (1)</td>
</tr>
</tbody>
</table>

**Does higher screw density improve radiographic and clinical outcomes in adolescent idiopathic scoliosis? A systematic review and pooled analysis**

*Ming Luo, MMed; Wengang Wang, MD; Mingkui Shen, MMed; Xin Luo, BS, and Lei Xia, MD*

Institute of Spinal Deformity, The First Affiliated Hospital of Zhengzhou University, Zhengzhou, Henan; and Department of Cardiovascular Medicine, The Central Hospital of Weihui, Hubei, P.R. China

Forest plot of operative time

Forest plot of ischial losses

Forest plot of hospital charges

SAQ appearance domain (p = 0.035) for the HD group, no significant differences were found in any SRS-22 domain scores in the study. Furthermore, the SRS-22 questionnaire was adopted from 4 other studies, and all of them reported similar results. The SRS-30 scores were reported in this study. The similar scores were found in the C1 and HD groups for all domains. Detailed information on QOL outcomes is shown in Table 3.
Clinical Results

Periapical-dropout Screws Strategy For 3-Dimensional Correction of Lenke 1 Adolescent Idiopathic Scoliosis in Patients Treated by Posterior Spinal Fusion

Thamrong Lertudomphonwan, MD, Viral V. Jari, MD, Peter F. Sturm, MD, and Saural Patel, MBBS, MS (Orth)

Clinical Results

Three-Dimensional Correction in Patients With Lenke 1 Adolescent Idiopathic Scoliosis

Comparison of Consecutive and Interval Pedicle Screw Instrumentations

Savvai Bros-Keating, MD, Yihan Song, MD, and Saural Patel, MBBS, MD

Clinical Results
Conclusions

- The cost of scoliosis surgery has increased dramatically over the past 2 decades
- We began using more implants without scientific justification
- Low implant density constructs have been proven to be radiographically and clinically equivalent
- Locally high implant density at the apex of the deformity correlates with improved radiographic and clinical outcomes

Can we produce equivalent or better clinical results with less pedicle screws?

YES!
Thank you

References


Augmented Reality in Spine Surgery

Thomas Noh, MD
Assistant Clinical Professor
John A Burns School of Medicine
Honolulu, HI

No Disclosures
Image Guided Spine Surgery

**Accuracy**
- Thoracolumbar pedicle screw 2mm accuracy of 90%+
  - 0-37% fluoro
- Help to understand complex anatomy in deformity and tumor cases
- Allows cervical pedicle screws, iliac bolts, S2 screws, SI fusions

**Radiation**
- Decrease radiation to OR staff and surgeon
  - 4.33 vs 0.33 mRem to surgeon (Smith et al.)
    - Intraop CT 5.15mSv per patent (Costa et al)

**Outcomes**
- O-arm vs freehand (Xiao et al)
  - Hospital stay (4.7 v 5.4)
  - Readmission (0.8% v 4.2%)
  - All cause reoperation (5.2% v 10.9%)
- ~$7,000/case savings

**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.

**Time**
- Increased time for preoperative planning and registration

**Ergonomics**

![Image of surgeons performing surgery]
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
**Accuracy**
- Clear visualization of subq anatomy
- Maintaining eyes on patient and operative field
- Most studies parallel accuracy of traditional IGS

**Ergonomics**
- Less shifting of surgeon’s attention
- Less line-of-sight issues

**Training**
- Valuable tool for training
- Reduces learning curve of challenging procedures

---

*Fig. 1. Prototype of the intraoperative extended reality visualization system.*
# Drawbacks...

<table>
<thead>
<tr>
<th><strong>Accuracy</strong></th>
<th><strong>Quality</strong></th>
<th><strong>Training</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable inaccuracy</td>
<td>Image quality, latency, low brightness or contrast issues</td>
<td>Steep learning curve for new adapters</td>
</tr>
<tr>
<td>Reregistration</td>
<td>Software issues</td>
<td>Next generation of surgeons unable to freehand?</td>
</tr>
<tr>
<td>Focal length limitations</td>
<td>Visual fatigue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Headset weight</td>
<td></td>
</tr>
</tbody>
</table>
THANK YOU!

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

Hawaii Pacific Health
- Russell Woo, MD

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

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

ThomasNohMD
noht@hawaii.edu


PROXIMAL JUNCTIONAL KYPHOSIS

Etiology, Risk Factors & Prevention

Emmanuel Menga, M.D.

Associate Professor of Orthopaedic Surgery
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

Financial Disclosure

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

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

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

Lowe & Kasten Spine 1994
Proximal Junctional Kyphosis

Proximal junctional sagittal Cobb angle $\geq 10^\circ$ or proximal junctional sagittal Cobb angle at least 10° greater than the preoperative measurement.

Bridwell et al. investigated $\geq 20^\circ$ as the critical angle (ASD)

Helgeson et al. proposed $>15^\circ$ as the new critical angle
**Epidemiology**

- **Proximal Junctional Kyphosis (PJK)**

- **Proximal Junctional Failure (PJF)**
  - Bridwell et al. Prevalence of 27.8% ADS at 3-5yrs.

- **Topping-off Syndrome**
  - Helgeson et al. Failure to fully develop of vertebral anterior, middle, and posterior columns.

- **Acute Collapse**
  - Lonner et al. Incidence 20-39% ADS at 3-5yrs.

- **PJF Failure (PJF)**
Timing of PJK development

- Most commonly occur within 2 years of surgery
- 43% Idiopathic scoliosis 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): Soft tissue failure (34%) (p = 0.02)
- Proximal Thoracic (T7-5) UIV: Subluxation
- Thoracolumbar (T7 to L2) Fracture (66%) (p = 0.00)
- Diaphragm Thoracic (T9-11) UIV: Compression fracture

53% local PJK angle after Adult spinal surgery

76% of PJK occurred within 3 months after surgery & accounted for Adult spinal deformity

59% of the local PJK angle occurred within 8 weeks of surgery in surgery

43% Idiopathic scoliosis developed PJK within the first year of surgery

Most commonly occur within 2 years of surgery
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

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

RISK FACTORS

Grading and type of PJK
- Grade C: increase angle ≥ 20°
- Grade B: increase angle 15-19°
- Grade A: increase angle 10-14°
Patient Specific Risk Factors

- Gender (male>female)
- Age
- BMI
- Osteopenia/Osteoporosis
- Sarcopenia
- Alcohol
- Cigarette smoking
- Proximal Instrumentation Level (LIV)
- Posterior Instrumentation
- Anterior/Posterior Instrumentation
- Pelvic Fixation (LIV)

Surgical Risk Factors

- Type of Instrumentation
- Integrity of the Posterior Ligamentous Complex
- Proximal Instrumentation Level (LIV)
Radiographic risk factors

Restoration of Sagittal Plane Alignment

Current literature largely based on Schwab criteria/sagittal modifiers

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

Radiographic Risk Factors
Prevention techniques (UIV)

- Osteopenia/Osteoporosis
- Global sagittal alignment

Prevention
Prevention

Fixation techniques (UIV)

- 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)

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

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
Current Concepts

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. *Average angle*: PJK at 2yrs 8.2° (-1 to 18) all screw construct stat sig vs 5.2° hybrid (p = 0.02) & 5° all hook construct (p = 0.014)
  2. *15° hookcritical angle*, Incidence of PJK: 0% all hooks, 2.5% hybrid, 8.1% pedicle derew & 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

(1) Gradual transition to the mobile segments above the UIV: Tethers

Buell et al. Operative Neurosurgery 2019

(2) Proximal segment ROM

- ROM TPH: 27% UIV - 1 to 97% at UIV
- ROM PS: 16% UIV - 1 to 91% at UIV

(3) Tether:

- TE-UIV+1: 14% of intact model UIV, 76% at UIV & 98% at UIV + 1
- TE-UIV+2: 10% at UIV, 51% at UIV & 97% at UIV + 1
- TE-UIV+3: 7% at UIV, 33% at UIV & 45% at UIV + 1

!) Reduce loading at the UIV

(ULV) Fixation techniques

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

Bess et al., J Neurosurgery Spine 2017

Buell et al., Operative Neurosurgery ‘19: 3-month followup. Non-tether 45% vs tether/spinous process 34% vs tether/crosslink 17%.

3-month followup (tether vs non-tether: 110° vs 90°, respectively) tether: 45% vs tether/spinous process 34% vs tether/crosslink 17%.

Buell et al., World Neurosurgery ‘19: 1 yr followup. PSC lower thoracic UIV (T9-11) junctional tether protective against PJK

Zaghloul et al, Orthopedics 16: 11-month followup. 0% PJK in Tethers at UIV

Prevention

Fixation techniques: Tethers at UIV
Prevention of Global Sagittal Alignment Cone of Economy

Prevention of Global Sagittal Alignment

Prevention of Global Sagittal Alignment
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 Sagittal Plane Alignment

- Restoration of Global sagittal alignment ($GSA = TK + LL + PI \leq 45^\circ$) (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

- Incomplete restoration of lumbar lordosis ($p = .004$)
- Overcorrection of the C7 sagittal balance as significant risk factors for PJK ($p = .04$)

Mendoza-Lattes et al. The Iowa Orthopaedic Journal 2007

---

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*)

---

**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
**Restoration of Sagittal Plane Alignment**

- HRQOL Measures

<table>
<thead>
<tr>
<th>TABLE V: Comparison of Postoperative Health-Related Quality of Life Scores Among GAP Categories in the Validation Cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Health-Related Quality of Life Measure</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>ODI</td>
</tr>
<tr>
<td>COMI</td>
</tr>
<tr>
<td>SRS-22 subtotal</td>
</tr>
<tr>
<td>SF-36 PCS</td>
</tr>
<tr>
<td>SF-36 MCS</td>
</tr>
</tbody>
</table>

**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

- Post-op: Jewett Brace when OOB, Continue Ca, Vit D
THANK YOU
Surgical Navigation in Spine Reconstructive Surgery: Uses Anteriorly and Posteriorly

Shane Burch MD
Professor in Residence
Orthopedic Surgery
UCSF Medical Center

OVERVIEW

OVERVIEW OF NAVIGATION  APPLICATIONS

TIPS AND TRICKS
COMPUTER ASSISTED SURGERY

- Intra-op Imaging
- Image Guidance
- Pre-op Planning
- Customized Procedures

Accuracy of Surgical Technique


Improve outcomes and quality of care
Decrease costs of care
PREVENTABLE COMPLICATIONS AND EASE OF PROCEDURE

NAVIGATION IS A TOOL
PREDICTABLE

OBTAINING REGISTRATION

MAINTAINING REGISTRATION

PREDICTABLE
WHY USE NAVIGATION?

- Anatomy is challenging
- Efficiency
- Accuracy
- Predictable
- Avoid radiation
- Osteotomy planning
- Custom implants
- MR merge technology
- Guidewireless Perc Screws
- Improved pedicle fill
- Improved construct
- Fusion mass
- 4 rod construct
- 5AU Screws
- SAI Screws
- SAI Screws
- Evrydoby has a Mike Tyson punch in the face
**EVOLUTION OF IMAGE GUIDANCE**


**TIME TO EVOLVE**

**BACKGROUND**

- Alignment of co-ordinate systems
  - Head to Frame
  - Frame to Image

- Frame in image

- Limited structures
FRAME-LESS REGISTRATION

• Physical Space – the patient – coordinate system \((P)\)
• Image Space – the scan - coordinate system \((Q)\)
• Tracker Space – Robotic arm; navigated tool

• Registration
  – Process of aligning these coordinate systems
  – Mathematical – a transform is required (rotation matrix plus a linear translation)
  – Defining error in the alignment process due to assumptions of fiducials

IMAGE COORDINATES
PHYSICAL SPACE COORDINATES

FIDUCIALS

• Markerless Pair Point Registration—
  – Surface registration

• Marker Based Pair Point Registration –
  – Fiducial screws embedded in bone
  – Frames attached to bone
  – Frames attached to skin

• Image to Image Registration
  – Image overlay with fiducials
ALIGNING IMAGE SPACE WITH PHYSICAL SPACE

TRANSFORMATION

\[ \varphi(\bar{Q}_i) = B \cdot \bar{Q}_i + \bar{y} = \bar{P}_i \]

Rotation  Linear translation
**INTRINSIC REGISTRATION ERROR**

- **Fiducial Localization Error (FLE)**
  - Pre Transform
  - Optics
  - Spheres
  - Number of fiducials

- **Fiducial Registration Error (FRE)**
  - Scan distortion
  - RMS error (mm) - CALCULATED

- **Tracker Registration Error (TRE)**
  - Not uniform; ERROR NOT KNOWN!!
  - Based on distance from fiducials

**ERROR:** 0.5 – 2.0mm

---

**COMMON EXTRINSIC ERRORS**

1. Patient positioning
2. Image quality / radiation exposure
3. Line of Sight - reference frame location
4. Reference frame stability
5. Distance from the reference frame
6. Deformation of the spine – ant/post vs rotation
7. Deformation of navigated instrument
8. Using the correct views

**ERROR:** >5mm
SURGICAL AND IMAGING WORKFLOW

CO-PILOTTING THE NAVIGATION OR ROBOTIC SYSTEMS....

- PROBE
- DRILL GUIDE
- DRILL
- TAPS
- OSTEOTOMES
- PAC NEEDLE
- DRIVERS

- TLIF
- LLIF
- ATP
- DISC PREP SETS
- MR merge
BUILD A TEAM – GET A CO-PILOT
The Navigated Oblique Lumbar Interbody Fusion: Accuracy Rate, Effect on Surgical Time, and Complications

INTRODUCTION

The purpose of this study was to assess the accuracy rate of the Navigated Oblique Lumbar Interbody Fusion (OLIF) technique in a cohort of patients undergoing lumbar fusion surgery. The study included 50 patients who underwent OLIF fusion using the EpiNav navigation system. The accuracy of the surgical navigation system was evaluated by comparing the planned and actual placement of the interbody cages. The study found that the navigation system was highly accurate, with a mean deviation of 1.3 mm from the planned trajectory.

MATERIALS AND METHODS

This study was a retrospective review of medical records of patients undergoing lumbar fusion surgery at our institution. The navigation system used was the EpiNav system, and the interbody cages used were the Dynamic Spinal Aligner (DSA) cages. The study was approved by the institutional review board.

LOCALIZING TUMOR
IMAGE TO IMAGE REGISTRATION
WHAT ABOUT MIS?
2nd Stage Perc Screws

Navigation: Guidewires Optional

A virtual guide wire is placed
THE AGE OF PRECISION MEDICINE

Theory

Technique
PLANNING AND EXECUTING AN OSTEOTOMY?

PI=65°
LL=41°
PT=30°

20° AT BASE OF L3

PI=65°
LL=41°
PT=30°
SFA=20°
FROM PLAN TO REALITY

REPRODUCIBLY OBTAINING PLAN?

PLAN AND EXECUTION OF PSO
IMAGE GUIDED CUTS

OSTEOTOMY THROUGH FUSION MASS

rostral

TP

20°

lamina

pedicle

L2

L4

caudal
TECHNICAL CONSIDERATIONS - PSO

PSO - Fusion Mass
Pedicle fixation - planning
SAI screws / Iliac fixation
4 rod construct
Alignment Planning and Execution

Navigation

REPRODUCIBLE APPROACH
LIMITATIONS OF NAVIGATION

• Intrinsic errors within any navigation system – error small
• Extrinsic errors (user error) are most common and problematic
• Segmental motion – requires an additional scan
• Workflow changes to avoid segmental motion

SUMMARY

• Build a CONSISTENT team – with a co-pilot
• Navigation is for both anterior and posterior approaches
• The above strategies augment the skills of a surgeon to complete complex procedures efficiently and predictably
THANK YOU
POSTERIOR ONLY ADULT RECONSTRUCTION: STRATEGIES TO OBTAIN OPTIMAL RESULTS

LAWRENCE G. LENKE, MD
PROFESSOR AND CHIEF OF SPINAL SURGERY
CHIEF OF SPINAL DEFORMITY SURGERY
COLUMBIA UNIVERSITY MEDICAL CENTER

SURGEON-IN-CHIEF
THE DANIEL AND JANE OCH SPINE HOSPITAL
NYP/ALLEN

UCSF CME PEDIATRIC AND ADULT SPINE SURGERY COURSE
AUGUST 4-7, 2021

DISCLOSURES
LAST 36 MONTHS

• Royalties: Medtronic (substantial), Quality Medical Publishing (minor).
• Consulting: Medtronic, EOS Technologies, Abyrx, Acuity Surgical (monies directed to a charitable foundation)
• Grants: EOS Technologies, SSS Foundation, ISSG Foundation, AOSpine,
• Board: OREF, GSO, SSS
• Philanthropic /Society Research Funding: Fox Family (Prospective Pediatric Spinal Deformity study); AOSpine & SRS (Scoli-Risk 1 study).
• Travel/Accommodations: AMCICO, AOSpine, BroadWater, COA, DePuy Synthes Spine, Medtronic, SOSORT, SRS, SSF, The Spinal Research Foundation.
POST. ONLY TX. OF SPINAL DEFORMITY

- Pedicle Screws – “Stabilizers”
- Posterior Osteotomies – “Carpentry”
  - PCOs (SPOs/Ponté Osteotomies)
  - PSO
  - VCR
- Correction Techniques for Sagittal/Coronal/Axial Plane
- Bone Graft: Auto/Allo/BMP
- Multimodality SCM – “Safety”
- All Deformities can be Corrected from a Post. Only Approach…..Last Formal Ant. Approach: 2000!

VENTRAL PEDICLE SCREW STARTING POINT

- Start Screw Placement more VENTRAL by Removing Sup. Facet/TP Junction Bone (and saving for Bone Graft) and thus being able to start CLOSER to the TARGET which is the Vertebral Body Ventral to the Spinal Canal!

55 Y/O SEVERE THORACIC HYPERKYHOSIS-MM

PSF C2-SAC/MULTILEVEL PCO’S/L5-S1 TLIF
3 TYPES OF SPINAL OSTEOTOMIES

• **PCO** – Posterior Column Osteotomy
• **PSO** – Pedicle Subtraction Osteotomy
• **VCR** – Vertebral Column Resection

SCHWAB OSTEOTOMY CLASSIFICATION: 3 MAIN TYPES

6 Grades of Destabilization:
1. Partial facet joint
2. Complete facet joints - **PCO**
3. Partial body# - **PSO**
4. Partial body and disc# - **PSO**
5. Complete body + discs# - **VCR**
6. >1 body, adjacent# - **VCR**

SELECTING THE TYPE OF OSTEOTOMY(IES)

- Type of Deformity – Scoliosis/Kyphosis/Lordosis
- **Magnitude** – Cobb measures
- **Stiffness** – Determined preop & intraop
- Coronal/Sagittal/Combined Imbalance
- **Angularity** vs. Smooth/roundness
- Bone Density – Proxy for PS purchase
- Operative Goals
- Surgeon Experience/Comfort level
- Minimization/Avoidance of complications

PREOP X-RAY/CLINICAL FLEXIBILITY ASSESSMENT

**Spinal Flexibility**

- Upright
- **Supine (X-RAYS/MRI/CT)**
- Push-Prone
- Side-Bending
- Traction
- Hyperextension Bolster (kyphosis)
- Hyperflexion Bolster (lordosis)

Flexible(A)  
vs.

Stiff(B)  
vs.

Stuck/Fused(C)

Silva, Lenke et al JNS Spine 2011
UPRIGHT SUPINE

T6-T10: 13
T10-L3: 32

T2-T12: 22
T12-S1: 35
PH: 64
PT: 35

T6-T10: 3
T10-L3: 22

PI: 64
PT: 35

SUPINE

T12-S1: 48
INCREASING LUMBAR LORDOSIS BY 18 DEG BY INTRAOP POSITIONING!

<table>
<thead>
<tr>
<th>Position</th>
<th>Preoperative</th>
<th>Intraoperative</th>
<th>Postoperative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upright</td>
<td>Supine</td>
<td>Prone</td>
</tr>
<tr>
<td>Increased lordosis group</td>
<td>25.9º ± 19.5</td>
<td>40.0º ± 19.8*</td>
<td>-43.1º ± 16.5*</td>
</tr>
<tr>
<td>Unchanged lordosis group</td>
<td>-4.2º ± 15.8</td>
<td>53.8º ± 15.7</td>
<td>-50.3º ± 14.8</td>
</tr>
</tbody>
</table>


INTRAOP POSITIONING + FACET RELEASES + INSTRUMENTED CORRECTION

UPRIGHT SUPINE INTRAOP POSTOP
BASIC POST CORRECTION TECHNIQUE BIOMECHANICS

- **Distraction** – Concavity = “Kyphogenic”
- **Compression** – Convexity = “Lordogenic”
- **Cantilever Rod Application** = “Lordogenic”
- **Translation Forces** = Post/Ant/Lat/Medial
- **In-Situ Rod Contouring** = Post/Ant/Lat/Med
- **Rod Rotation Maneuvers** = Kypho/Lordo
- **Apical Derotation Maneuvers** = Axial Correction

SPINAL DEFOMITY CORRECTION

- Correction Maneuvers all Performed with Sequence of Rod placement and Force application:
  - **Sagittal Plane** 1\textsuperscript{st}, **Coronal Plane** 2\textsuperscript{nd} and **Axial Plane** 3\textsuperscript{rd}
### 5 STEP RADIOGRAPHIC ANALYSIS FOR SPINAL DEFORMITY CORRECTION

1. **Preop Standing**
2. **Preop Supine**
3. **Intraop Pre-Rod Insertion**
4. **Intraop Post-Rod Insertion**
5. **Postop Standing**

### PCO Gr. 2
(N= > 1000 Cases)

1. **PCO** – Removal of Post Ligaments (interspinous, ligamentum flavum,) & facets (complete)
2. Referred to as **SPO** – Smith-Petersen Osteotomy (Fused joints) or **PO** – Ponte Osteotomy (Unfused)
3. Used throughout the entire Thoracic/Lumbar Spine
4. Must have “mobile” Disc spaces!
ADULT IDIOPATHIC SCOLIOSIS

UPRIGHT
SUPINE
PUSH-PRONE
DAR 80/7 = 11.4 & TYPE 1 SC SHAPE

CANTILEVER CORRECTION OF TL KYPHOSIS
POSTERIOR TRANSLATION OF THORACIC LORDOSIS TO CREATE THORACIC KYPHOSIS AND CORRECT SCOLIOSIS

THORACIC DISTRACTION ON CONCAVITY AND TL COMPRESSION ON CONVEXITY
IN-SITU CORONAL CONTOURING OF THE THORACIC AND TL/L CURVES

ADULT IDIOPATHIC SCOLIOSIS
PRE & POST LAT/CLIN PICS

ADULT IDIOPATHIC SCOLIOSIS/THORACIC HYPERKYPHOSIS
1. RIGHT ROD PLACEMENT WITH LUMBOSACRAL CONVEX COMPRESSION FORCES APPLIED

2. LEFT ROD PLACEMENT WITH LUMBOSACRAL CONCAVE DISTRACTION APPLIED
3. LEFT ROD CANTILEVER CORRECTION OF TL CURVE WITH CONVEX COMPRESSION

4. RIGHT ROD CAPTURED TO TOP OF CONSTRUCT WITH CANTILEVER KYPHOSIS CORRECTION
5. **APICAL TRANSLATION OF TL CURVE TO 3**\textsuperscript{RD} **ROD**

6. **ADDING OF 4TH ROD TO LUMBAR/LS REGION**
Primary deformity – flexibility???
ADULT DEGEN LUMBAR KYPHOSCOLIOSIS

T1-SAC/L5-S1 TLIF/ T10-L4 PCOs

“KICKSTAND ROD”
Radiographic and Clinical Outcomes of Posterior Column Osteotomies (PCO’s) in Spinal Deformity Correction: Analysis of 128 Patients

Ian G. Dorward, MD; Lawrence G. Lenke, MD; Geoff E. Stoker, BS; Woojin Cho, MD PhD; Brenda A. Sides, MA; Linda A. Koester, BS

18th IMAST
Copenhagen, Denmark
July 13-16th, 2011

SPINE 2014
**PCO’S: SAGITTAL CORRECTION**

- Not all PCOs are created equal!
- Overall mean $8.8^\circ \pm 7.2^\circ$
- Correction affected by age
  - $10.2^\circ \pm 7.8^\circ$ per level for patients $<$21 years vs. $7.7^\circ \pm 6.3^\circ$ for $\geq$21 ($P<0.0001$)
- Correction affected by Region of Spine ($P<0.0001$), as shown
- Dorward/Lenke et al. SPINE 2014

---

**PSO Gr. 3/4 (N>250)**

1. Remove Post. ligaments/facets/pedicles and decancellate vertebral body
2. Allows simultaneous correction of Coronal & Sagittal plane stiff deformities, but utilized primarily for Fixed Sagittal Imbalance = Flatback Syndrome vs. Fixed Combined Coronal/Sagittal Imbalance
3. Must remember that although osteotomies through bone and heals readily, motion segments above/below may not fuse, especially with facet excision/open discs anteriorly!
4 TYPES OF PSO’S (Gr. 3, 4 and 4+)

• Unilateral PSO
• Standard PSO- Gr. 3
• Extended PSO- Gr. 4
• “Sandwich” PSO- Gr. 4 + TLIF Below
Lumbar AdIS- No Prior Treatment

UPRIGHT

SUPINE
UPRIGHT SUPINE

PSF T3-SAC/L2 UNILAT PSO/ PCO’S T5-T11 & L3-SAC/DECOMP/TLIF
L4-SAC

LT

LT
4 TYPES OF PSO’S (Gr. 3, 4 and 4+)

• Unilateral PSO
• Standard PSO- Gr. 3
• Extended PSO- Gr. 4
• “Sandwich” PSO- Gr. 4 + TLIF Below

S/P PSF T10-L5: FIXED SAGITTAL IMBALANCE

PI = 85°/LL = -16°/PT = 35°
L4 PSO/PSF T10-SAC/ILIUM

4-ROD TECHNIQUE

AGE 73 – SPINAL/PELVIC/LE REALIGNMENT!
4 TYPES OF PSO’S (Gr. 3, 4 and 4+)

• Unilateral PSO
• Standard PSO- Gr. 3
• Extended PSO- Gr. 4
• “Sandwich” PSO- Gr. 4 + TLIF Below

S/P L3-L5 PSF/TLIF: COMBINED IMBALANCE: TREATMENT

PI = 47°/PT = 38 Deg/PI-LL = 74 Deg
5 STEP RADIOGRAPHIC ANALYSIS FOR SPINAL DEFORMITY CORRECTION

1. Preop Standing
2. Preop Supine
3. Intraop Pre-Rod Insertion
4. Intraop Post-Rod Insertion
5. Postop Standing

PSF T4-SAC/L5-S1 TLIF/T10-L2 PCO’S/L3 EXTENDED PSO (GR. 4)
4 TYPES OF PSO’S (Gr. 3, 4 and 4+)

• Unilateral PSO
• Standard PSO- Gr. 3
• Extended PSO- Gr. 4
• “Sandwich” PSO- Gr. 4 + TLIF Below
S/P T4-SAC/DWI/ALL IMPLANTS REMOVED

TYPE C FLEXIBILITY: FUSED
EXPOSURE/PROTECTION OF L L5 ROOT

CEPHALAD

CAUDAD

left L5 pedicle corridor

L5 BODY DECANCELLATION

...
NO LATERAL DISSECTION!

MAINTAIN SPINE STABILITY!
RIGHT L5 ROOT PROTECTION FOR PEDICLE EXCISION

RIGHT L5 BODY DECANCELLATION
POSTERIOR WALL REMOVAL

INTRABODY/DISC CAGE PLACEMENT
POSTERIOR COMPRESSION/PSO CLOSURE......

CHECK DURAL SAC AND NERVE ROOTS AGAIN.....AND AGAIN!

CHECK ROOTS FOR BOTH EXTERNAL COMPRESSION AND TENSION
VCR: Grade V and VI

• Removal of an Apical Vertebra(e) Thereby Separating the Spine into 2 Sections That can be Shortened and then Rejoined to Correct Even the Most Severe Spinal Deformities

POST-RADIATION SPINE DEFORMITY
PSF T8-SAC/L2 VCR/TLIF’s L3-SAC

5 yr po
20°

5 yr po
SVA = 15 mm
PI = 15°

-30°
Radiographic and Clinical Outcomes of 3-column Osteotomies (PSO/VCR) at a Minimum 5 Year Follow-up

Kevin O’Neill, MD; Lawrence G. Lenke, MD; Keith H. Bridwell, MD; Ian Dorward, MD; Sang Kim, MD; Brian Neuman, MD; Linda Koester, BS

Washington University Dept. Of Orthopedic Surgery
Section of Spinal Surgery
St. Louis, MO

118 pts: 96 PSOs/22 VCRs

SRS 2013, Vancouver B.C., July 2013/SPINE 2014

OUTCOMES @ 5 YRS PO

<table>
<thead>
<tr>
<th>ODI</th>
<th>SRS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Post-Operative Time
POST. ONLY TX. OF SPINAL DEFORMITY

- Pedicle Screws – “Stabilizers”
- Posterior Osteotomies – “Carpentry”
  - PCOs (SPOs/Ponté Osteotomies)
  - PSO
  - VCR
- Correction Techniques for Sagittal/Coronal/Axial Plane
- Bone Graft: Auto/Allo/BMP
- Multimodality SCM – “Safety”
- All Deformities can be Corrected from a Post. Only Approach…..Last Formal Ant. Approach: 2000!

THANK YOU!

LL2989@COLUMBIA.EDU
SPINAL-DEFORMITY-SURGEON.COM