Proximal Junctional Kyphosis (PJK) Prevention

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Disclosures

- Consultant - Zimmer / Biomet, DePuy Synthes Spine, Amendia, Stryker
- Stock - Innovative Surgical Solutions, Safe Wire, Vivex
- Royalties - Biomet

Acute Proximal Junctional Failure

- Acute proximal junctional failure (APJF) was recently defined by the International Spine Study Group (ISSG) as:
  - Post-operative fracture of the upper instrumented vertebrae (UIV) or UIV + 1
  - UIV implant failure
  - Proximal junctional kyphosis (PJK) increase > 15 degrees
  - Need for proximal extension of the fusion within 6 months of surgery

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REVIEW ARTICLE

Proximal junctional kyphosis following adult spinal deformity surgery

Samuel K. Cho · John I. Shin · Yongjung J. Kim

- A systematic review was performed to assess the prevalence, risk factors, and treatments of PJK.
- Analyzed 33 studies that reported the prevalence rate, risk factors, and discussions on PJK following spinal deformity surgery.
- **Prevalence rates varied widely from 6 to 61.7 %.**
- **Clinical outcomes for patients with PJK were not significantly different from those without PJK.**
  - One recent study revealed that **adult patients with PJK experienced more pain.**
- **Risk factors for PJK included**
  - Increased age at operation
  - Low bone mineral density
  - Shorter fusion constructs, UIV below L2
  - Inadequate restoration of global sagittal balance.
- Prevalence of PJK was high but not as clinically significant.

Careful and detailed preoperative planning and surgical execution may reduce PJK in adult spinal deformity patients.

Predictive Factors for Acute Proximal Junctional Failure after Adult Deformity Surgery with Upper Instrumented Vertebrae in the Thoracolumbar Spine*

Prokopis Annis[1] Brandon D. Lawrence[1] William R. Spiker[1] Yue Zhang[2] Wei Chen[2]
Michael D. Daubs[3] Darrel S. Brodke[1]

- 135 consecutive patients with minimum 2-year follow-up, fusions were divided into 3 cohorts based on the UIV location (T9–T10 vs. T11–T12 vs. L1–L2).
- **The incidence of APJF was 38.5%, with a trend toward higher APJF in the T9–T10 group (p . 0.07)**
- **UIV was at T10, the incidence of APJF was 57.1%,** significantly higher than T9 and T11 (p=0.03 and p=0.01).
  - Overall revision rate for APJF was 17%,
- **Risk factors for APJF**
  - Pre-op sagittal vertical axis > 5 cm
  - Post-op PJA > 5 degrees
  - Thoracic kyphosis > 30 degrees
  - Instrumentation to the pelvis as risk factors for APJF.
  - Greater correction of lumbar lordosis (LL)
- **Fracture at the UIV lead to the highest revision rate.**
- **PJK > 15 degrees WITHOUT fracture or hardware failure had the longest revision-free survival (2-5 years, 100%).**

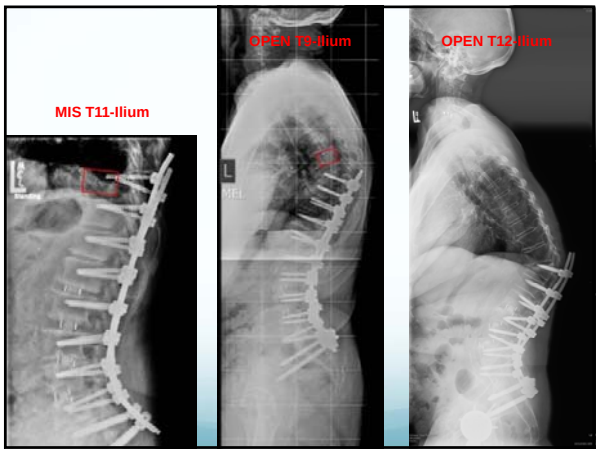
Post-op PJA > 5 degrees and greater correction of LL are independent risk factors for APJF.

Neurosurg Focus 36 (5):E9, 2014

Long fusion from sacrum to thoracic spine for adult spinal deformity with sagittal imbalance: upper versus lower thoracic spine as site of upper instrumented vertebra

Takahito Fujimori, M.D.,[1,2] Shinichi Inoue, M.D.,[1,3] Hai Le, B.A.,[3] William W. Schairer, M.D.,[1] Sigurd H. Berven, M.D.,[1] Bobby K. Tay, M.D.,[1] Vedat Deviren, M.D.,[1] Shane Burch, M.D.,[1] Motoki Iwasaki, M.D.,[2] and Serena S. Hu, M.D.[1]

- UIV for the Upper Thoracic (UT) group ranged from T-1 to T-6
- Lower Thoracic (LT) group it ranged from T-7 to T-12
- **The LT group tended to have more proximal junctional kyphosis (PJK).** Radiographic PJK was 32% in the UT group and 41% in the LT group (p = 0.4).
- Surgical PJK was 6.4% in the UT group and 10% in the LT group (p = 0.6)
- Both the UT and LT groups demonstrated significant improvement in clinical and radiographic outcomes.
- **Improvement in clinical outcomes were not significantly different between the 2 groups.**



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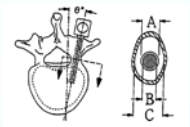
The Effects of Pedicle Screw Fit
An *In Vitro* Study

Anna G. U. Brantley, MS,* Jack K. Mayfield, MS, MD,†
James B. Koeneman, PhD,* and Kathleen R. Clark, MS†



- The use of longer screws increased fixation stiffness if the **screw fills the pedicle by > 70%.**
- The use of wider screws increased fixation stiffness if the **screw penetration depth is > 80%.**

Acta Neurochir (2016) 158:465–471
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EXPERIMENTAL RESEARCH - SPINE

Biomechanical evaluation of fixation strength among different sizes of pedicle screws using the cortical bone trajectory: what is the ideal screw size for optimal fixation?

Keitaro Matsukawa[1] · Yoshiyuki Yato[2] · Hideaki Imabayashi[1] · Naobumi Hosogane[1] · Yuichiro Abe[3] · Takashi Asazuma[2] · Kazuhiro Chiba[1]

- **Larger-diameter screws increased the pullout strength and vertebral fixation strength and decreased the equivalent stress around the screws**
  - No statistically significant differences between 5.5-mm and 6.5-mm screws.
  - The screw diameter was a factor more strongly affecting the fixation strength of CBT than the screw fit within the pedicle (%fill).
  - Longer screws significantly increased the pullout strength and vertebral fixation strength in axial rotation.
  - The amount of screw length within the vertebral body (%length) was more important than the actual screw length, contributing to the vertebral fixation strength and distribution of stress loaded to the vertebra.
- Fixation strength of CBT screws varied depending on screw size. The ideal screw size for CBT is a diameter larger than 5.5 mm and length longer than 35 mm, and the screw should be placed sufficiently deep into the vertebral body.

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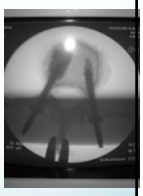
Primary Pedicle Screw Augmentation in Osteoporotic Lumbar Vertebrae

Biomechanical Analysis of Pedicle Fixation Strength

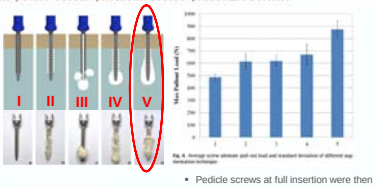
Daniel J. Burval, MD, Robert F. McLain, MD, Ryan Milks, BSBME, and Serkan Inceoglu, PhD

- Pedicle screws placed in osteoporotic vertebrae had higher pullout loads when augmented with the kyphoplasty technique compared to transpedicular augmentation (1414 ± 338 versus 756 ± 300 N, respectively; P < 0.001). **Kyphoplasty > transpedicular.**
- An unpaired t-test showed that fatigued pedicle screws in osteoporotic vertebrae augmented by kyphoplasty showed higher pullout resistance than those placed in healthy control vertebrae (P=0.002).
- Both kyphoplasty type augmentation (P=0.007) and transpedicular augmentation (P=0.02) increased pullout loads compared to pedicle screws placed in non-augmented osteoporotic vertebrae when tested after fatigue cycling.
- **Pedicle screw augmentation with PMMA improves the initial fixation strength and fatigue strength of instrumentation in osteoporotic vertebrae.**



Pedicle screw cement augmentation. A mechanical pullout study on different cement augmentation techniques

Francesco Costa[a,*], Alessandro Ortolina[a], Fabio Galbusera[b], Andrea Cardia[a], Giuseppe Sala[c], Franco Ronchi[d], Carlo Uccelli[d], Rossella Grosso[d], Maurizio Fornari[a]



- Group I: No cement.
- Group II: Retrograde filling of tapped area (1.5 cc cement) before screw insertion.
- Group III: Cannulated and fenestrate screw fully inserted before 3 cc cement injection.
- Group IV: Trocar and retrograde filling of 3 cc of cement before screw insertion.
- Group V: Fenestrated trocar and retrograde filling of 3 cc of cement before screw insertion.

- Pedicle screws at full insertion were then tested for axial pullout failure using a mechanical testing machine.
- A total of 30 screws were tested.
- The results of pullout analysis revealed better results of all groups with respect to the control group.
- **Statistically stronger pullout in Group V compared to Groups I, II, III, IV (p = 0.001).**

Spine
Biomechanics

Biomechanical Risk Factors for Proximal Junctional Kyphosis

A Detailed Numerical Analysis of Surgical Instrumentation Variables

- Biomechanical FEA analysis
  - Pedicle screws
  - Proximal transverse process hooks
  - Transition / tapered rods (5.5mm to 4mm)
- 4 biomechanical indices were assessed
  - Proximal junctional kyphotic angle
  - Thoracic kyphosis
  - Proximal flexion force
  - Proximal flexion moment
- Recommendations to decrease the rate of PJK:
  - **Preserve the posterior intervertebral elements (soft tissue) at and above the UIV.**
  - **Preserve the proximal facets and posterior ligaments.**
  - **Use transverse process (TP) hooks or tapered rods at the UIV vs. pedicle screws.**
  - Reduce the sagittal preoperative rod curvature allows a decrease of the biomechanical indices thought to be involved in the pathomechanisms of PJK.

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Evaluation of Proximal Junctional Kyphosis in Adolescent Idiopathic Scoliosis Following Pedicle Screw, Hook, or Hybrid Instrumentation

Melvin D. Helgeson, MD,* Suken A. Shah, MD,† Peter O. Newton, MD,‡ David H. Clements, III, MD,§ Randal R. Betz, MD,¶ Michelle C. Marks, PT, MA,‡ Tracey Bastrom, MA,‡ and The Harms Study Group

- The incidence of PJK (kyphotic deformity greater than 15º) **in AIS**
  - 0% in group 1 (hooks only)
  - 2.3% in group 2 (hybrid with hooks and pedicle screws)
  - 5.6% in group 4 (P=0.18) pedicle screws except hooks at the UIV
  - **8.1% in group 3 (pedicle screw only)**
  - Patients with PJK had an increased body mass index compared with those who did not meet criteria for PJK (P=0.013).
- **Adjacent level proximal kyphosis was significantly increased with pedicle screws only**, but the clinical significance of this is unclear.
- A potential solution is the substitution of hooks at the upper-instrumented vertebrae, but further investigation is required.

Evaluation of pullout strength and failure mechanism of posterior instrumentation in normal and osteopenic thoracic vertebrae

Laboratory investigation

Orestes Paixon, M.D., Ph.D.,[1] Panayiotis P. Tsitsopoulos, M.D., Ph.D.,[1,2] Michael R. Zindrick, M.D.,[3] Leonard I. Voronov, M.D., Ph.D.,[3,4] Mark A. Lorenz, M.D.,[3] Robert M. Havey, B.S.,[3,4] and Avinash G. Patwardhan, Ph.D.[3,4]

Group	Transpedicular Screws	Hooks	Sublaminar Wires	Screws & Wires	Average
BMD overall (mg/ml)	166.8 ± 64.4	151.3 ± 62.8	175.3 ± 57.3	173.1 ± 59.9	166.6 ± 60.7
Group A					
no. of vertebrae	10	11	7	8	
BMD (mg/ml)	113.2 ± 29.1	102.8 ± 32.2	111.1 ± 28.7	110.5 ± 34.6	109 ± 30.2
pullout strength (N)	446.8 ± 200.8	484.9 ± 207	478 ± 142.1	486 ± 169.7	473.2 ± 179.2
Group B					
no. of vertebrae	10	9	13	12	
BMD (mg/ml)	220.3 ± 39.1	230.3 ± 30.2	209.9 ± 33	214.8 ± 26.2	213.7 ± 31.4
pullout strength (N)	1457.1 ± 546.4	1617.9 ± 340.1	1520 ± 506.3	1583.4 ± 589.8	1416.5 ± 554.6

* Group A = BMD < 150 mg/ml; Group B = BMD > 150 mg/ml.

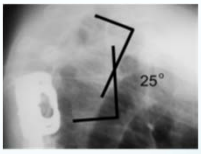
- In the osteopenic group, larger screws demonstrated greater resistance to pullout (p = 0.011). The most common failure mechanism in both groups was through pedicle base fracture.
- Bone quality is an important factor that influences stability of posterior thoracic implants. Fixation strength in the osteopenic group was one-fourth of the value measured in vertebrae with good bone quality, irrespective of the instrumentation used.
- In normal bone quality vertebrae, the **sublaminar hook / claw system dislocated with significantly less force** when compared with other spinal implants.

The Influence of Proximal Anchors on the Risk of Proximal Junctional Fracture in the Osteoporotic Spine

Biomechanical Comparison Between Pedicle Screws and Transverse Process Hooks

Jean-Marc Mac-Thiong, MD, PhD,†‡ Annie Levasseur, MScA,† Stefan Parent, MD, PhD,*†‡ and Yvan Petit, PhD†§*

- Biomechanical comparison above multi-level spinal instrumentation analyzing affects on PJK.
- Group 1 - Pedicle screws (AP)
- Group 2 - Transverse process hooks (PTPH)
- Bone density was similar between the AP and PTPH groups.
- Cyclic compression loading between 50 and 1000N at 1 Hz was applied to each of 24 instrumented spinal segments until obtaining a PJF.
- PJF occurred in 22 of 24 tested specimens.
- The number of cycles required to produce the PJF was similar between the AP and the PTPH Groups.



Tranvers process hooks failed to provide a significant impact over pedicle screws on top of multi-level pedicle screw constructs to decrease the risk of PJF.

RESEARCH—HUMAN—CLINICAL STUDIES

Praveen V. Mummaneni, MD*
Paul Park, MD†
Kai-Ming Fu, MD, PhD§
Michael Y. Wang, MD¶
Stacie Nguyen, MPH‖
Virginie Lafage, PhD#
Juan S. Uribe, MD**
John Ziewacz, MD, MPH*
on Behalf of the International Spine Study Group

Does Minimally Invasive Percutaneous Posterior Instrumentation Reduce Risk of Proximal Junctional Kyphosis in Adult Spinal Deformity Surgery? A Propensity-Matched Cohort Analysis

- 68 patients cMIS (perc screws) group, and 68 patients HYB (open screws) group compared from a multicenter database.
- Mean number of levels treated posteriorly was 4.7 for cMIS and 8.2 for HYB (P<0.001).
- Oswestry Disability Index scores were significantly improved in both groups.
- Radiographic PJK was defined as proximal junctional angle > 10
  - **Radiographic PJK developed in 31.3% of the cMIS and 52.9% of the HYB group (P=0.01).**
  - **Reoperation for PJK was 4.5% for the cMIS and 10.3% for the HYB group (P=0.20).**
- **Sub-group analysis for patients undergoing similar levels of posterior instrumentation in the cMIS and HYB groups found a PJK rate of 48.1% and 53.8% (P= 0.68)**
  - **Reoperation rate of 11.1% and 19.2%, respectively (P=0 .41)**
- Overall rates of radiographic PJK and reoperation for PJK were not significantly decreased with MIS pedicle screw placement.

However, a larger comparative study is needed to confirm that MIS pedicle screw placement does not affect PJK.

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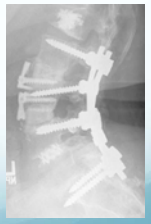
THE SPINE JOURNAL
The Spine Journal 8 (2008) 875–881

Clinical Studies

Proximal junctional acute collapse cranial to multi-level lumbar fusion: a cost analysis of prophylactic vertebral augmentation

Robert A. Hart, MD[a,*], Michael A. Prendergast, BA[b], Warren G. Roberts, MD[c], Gary M. Nesbit, MD[d], Stanley L. Barnwell, MD, PhD[e]

- 15 / 28 patients had prophylactic vertebroplasty cranial to the fused segment.
- **PJK requiring revision surgery occurred in 2 / 13 patients (15.3%)** treated without prophylactic vertebroplasty.
- **0 / 15 patients** undergoing prophylactic cement augmentation experienced PJK.
- **Revision surgery ($77,432) > prophylactic vertebroplasty ($46,240)**



Prophylactic vertebroplasty protected against PJK in this patient population.

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THE SPINE JOURNAL
The Spine Journal 13 (2013) 1897–1903

Basic Science

Use of vertebroplasty to prevent proximal junctional fractures in adult deformity surgery: a biomechanical cadaveric study

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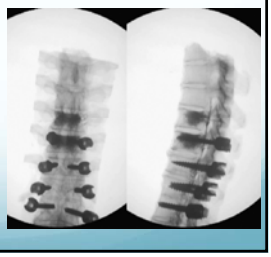
Received 19 September 2012; revised 3 April 2013; accepted 14 June 2013

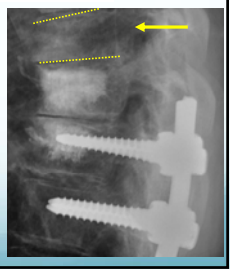
- Cadaveric study
- Cemented UIV & UIV + 1
- **Fractures occurred in 12 of 18 specimens**
  - **5 in the control group**
  - **6 in the one-level group**
  - **1 in the two-level group**
- These differences were statistically significant.



Spine
Deformity

Prevention of Acute Proximal Junctional Fractures After Long Thoracolumbar Posterior Fusions for Adult Spinal Deformity Using 2-level Cement Augmentation at the Upper Instrumented Vertebra and the Vertebra 1 Level Proximal to the Upper Instrumented Vertebra

- 51 patients met inclusion criteria
  - 19 patients - 2-level cement
  - 23 – No cement
  - 9 – Other (received cement-augmentation at a portion of the proximal extent of the fusion construct placed based on surgeon preference.
- **Revision rate for 2-level cement 0% vs. 19% for non-2-level cement (P=0.02).**
- After UIV adjustment, risks of PJF revision surgery were 13.1 times higher for "Other" (95% CI: 0.5–346.5, P = 0.12)
  - 9.2 times higher (95% CI: 0.4–239.1, P = 0.18) for no-cement.



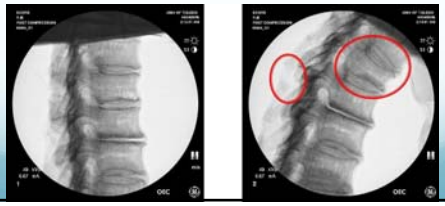
Reduced Rate of Proximal Junctional Fractures Above Long Instrumented Constructs Utilizing a Tapered Dose of Vertebral Cement – A Biomechanical Study

- Prophylactic vertebroplasty has been advocated to reduce PJK but cementation can result in the translation of stress cranial to the cemented "super-vertebra" that is created.

- We utilized a tapered dose of cement in T10, T9, and T8 to reduce junctional stress and the rate of proximal junctional fractures.

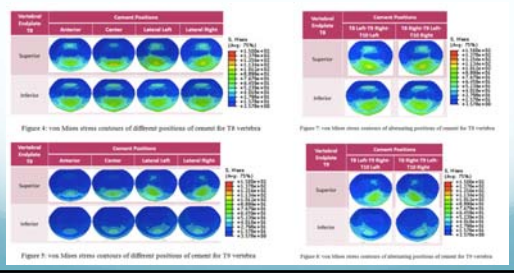
Results

- **There was a significant reduction in fractures in Group 3 vs 2 and 1 (0 vs. 5 vs. 5 fractures, p=0.0019, respectively).**
- Posterior ligamentous rupture occurred in 4 specimens in Group 3; 3 in Group 2; and 1 in Group 1.
- The mean peak load-to-failure values showed an increasing trend from Groups 1 to 3 (p=0.38).

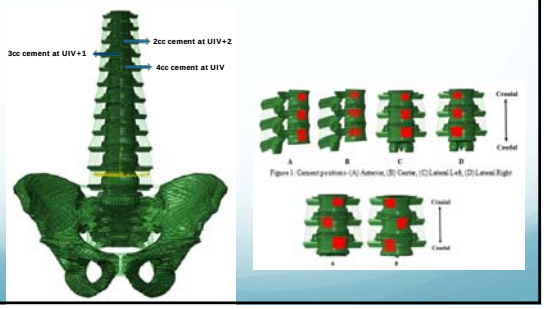


FEA Tapered Cement

T7 – No increased endplate stress
T8 – 33% reduction of endplate stress
T9 – 20% reduction of endplate stress

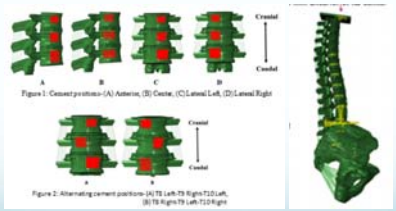


Location of Prophylactic Vertebral Cement Above Long-Instrumented Constructs Affects Junctional Endplate Stress: A Finite Element Model



Methods

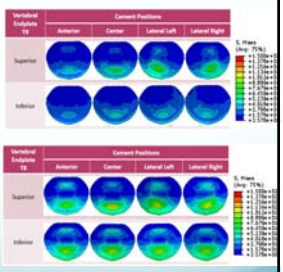
- Different cement configurations were simulated (central, anterior, lateral right, lateral left, and staggered).
- A compressive load was applied 10mm anterior to the center of the T6 vertebrae to simulate a flexion moment.



- Endplate stress and posterior ligamentous strain from T7 to T10 were analyzed.

Results

- Anteriorly placed cement resulted in a 26% decrease in max superior endplate stress at T9, and a 21% decrease at T8, vs centrally located cement.
- Max superior and inferior endplate stress at T7 was similar for anterior vs central cement.
- Posterior ligamentous strain was reduced by 2% at the T8-T9 level with anterior placement.
- Staggering the cement resulted in similar T7 - T10 endplates stress and ligament strain vs centrally placed cement.



Conclusions

- **Anteriorly placed prophylactic vertebral cement is advantageous when compared to the gold standard of centrally placed cement in this FE model.**
  - Stresses at the endplates of T8 and T9 reduced considerably with anteriorly placed cement.
  - Posterior ligamentous strain was also reduced at T8 - T9.
- The effect of anterior cement placement may reduce endplate stress clinically.
  - A decrease in maximal endplate stress is beneficial, and **translates to increase force required for endplate failure and possibly PJK.**

Conclusion

- Poor bone quality is concern in most ASD patients due to their age.
- Pedicle screws, particularly those augmented with cement, are biomechanically strong, but can create a stress riser, particularly in osteoporotic bone.
- Construct stiffness and poor bone quality are risk factors for PJK.
- **Tapered does cement technique in the UIV (4cc), UIV + 1 (3cc), and UIV + 2 (2cc) may protect the spine from PJK.**
- **Place cement in the anterior portion of the vertebral body.**

Conclusion

- Further clinical analysis is required.
- To date:
  - 11 patients with UIV at the T/L junction with tapered cement
  - Mean Dexa T-score -2.6
  - Mean follow-up 26 months
  - **No PJK**

Thank you