

2009 HTA TECHNOLOGY SELECTIONS

Background:

The Health Technology Assessment (HTA) program is a legislatively created program that seeks to ensure that health technologies purchased by state agencies are safe and effective, and that coverage decisions of state agencies are more consistent and transparent. The focus of the program is to rely on scientific, or evidence-based, information about safety and effectiveness to inform decisions and improve quality. An independent committee of eleven practicing health care clinicians uses the report and other information to review evidence regarding safety, efficacy, and cost-effectiveness of various medical procedures and/or equipment and determine if the state will pay for those procedures.

Technology Selection (Review or Re-review)

The HCA Administrator, in consultation with participating state agencies, selects technologies that undergo an evidence review, and may undergo a re-review. The independent committee can also be petitioned to include a technology for review or re-review, if not selected by the Administrator.

- State agency liaisons recommend potential technologies for prioritization and recommendation to the HCA Administrator. A priority ranking tool, with criteria based on legislative and other HTA program criteria, is used to rank the technologies.
- Interested individuals can petition the program to review a technology using the form located on the HTA website at: <http://www.hta.hca.wa.gov/ipp.html>. These petitions are also prioritized and a recommendation is made to the Administrator
- Recommendations are posted for public and committee comment. The HCA Administrator considers the agency recommendation and public comment and selects technology topics. Topics are posted on our HTA website.
- Interested individuals may also petition the clinical committee to re-consider a topic or re-review of a technology that the HCA Administrator decided not to select.

Prioritization Criteria:

HTA created a process and tools based on the legislative requirements and criteria that are widely used in technology assessment priority settings. Identification of criteria and use of priority tools makes the process explicit and increases transparency and consistency across decision-makers. The tools are intended to be used by the medical directors when making recommendations and by the clinical committee when making comments or selections of technologies. The technology scoring tool has a corollary set of Primary criteria and a set of Secondary criteria. The primary criteria are directly linked to the legislative mandates for the program to focus technology reviews where there are concerns about safety, efficacy, or cost effectiveness, especially relative to existing alternatives. See RCW 70.14.100. These criteria are also common to other technology assessment programs.

Re-review Criteria

Re-review criteria are included in a prioritization document and directly linked to the legislative mandate that technologies shall be selected for re-review only where evidence has since become available that could change a previous determination. Technologies are considered for re-reviews at least once every eighteen months. Re-reviews consider only evidence made available since the previous determination. See RCW §70.14.100.

- ~ Based on these legislation, the re-review criterion is directed at identifying those situations:
 - Where new evidence about a technology exists that was not available when the initial review was completed.
 - And there is at least some likelihood that the new evidence could result in a change to a previous determination

- Factors here could include potentially high impact new outcomes not previously considered; new clinical trials that are high quality and have results that are counter to trials included in review; new cost or agency impact results

Selection for 2009

- On September 23, 2008, the agency liaisons made recommendations on twelve potential technologies and two potential re-review technologies for prioritization.
- Topics and recommendations were posted to the website for comment.
- On December 12, 2008, the HCA Administrator selected seven topics for review and did not select any re-review topics. Selected topics are posted on our HTA website (<http://www.hta.hca.wa.gov/>).
- A stakeholder has requested that the clinical committee re-consider the Upright MRI as a topic for re-review.

2009 Re-review Recommendations:

The following re-review recommendations related to Upright MRI were made to the administrator.

Upright MRI	A PubMed literature scan was completed by the HTA clinical consultant. It did not reveal any significant new evidence that might lead to a different conclusion. No other issues or concerns raised at this time, and this is not recommended for re-review by medical directors at this time.
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The Administrator also reviewed public comments submitted by stakeholders and after that review agreed with the initial recommendation that there was not sufficient new evidence that would likely lead to a different conclusion to warrant a re-review.

January 6, 2009

Washington State Health Care Authority
c/o Leah Hole-Curry, Program Director,
Health Technology Assessment Program
Health Technology Assessment Committee
P.O. Box 42712
676 Woodland Square Loop SE
Olympia, WA 98504-2712

Re: Re-Review of Upright MRI Technology

Dear Health Technology Clinical Committee:

Please accept this letter as a formal request that the Health Technology Clinical Committee (HTCC) place the upright MRI technology for re-review on its 2009 agenda. This request is made pursuant to my conversation with Leah Hole-Curry, Program Director, Health Technology Assessment Program. The upright MRI technology was originally reviewed by the HTCC in 2007. In May 2007 the HTCC made a determination that the upright MRI would not be covered.

Since the May 2007 determination, additional studies and reports have been conducted and issued. I have attached for your review a copy of our October 22, 2008, letter sent to the Washington State Health Care Authority (HCA) requesting that the Administrator place the upright/positional MRI on the 2009 agenda. On December 12, 2008, the HCA Administrator issued a notice of selected health technologies to be reviewed in 2009, by the HTCC. The upright MRI was eligible for re-review but not placed on the 2009 agenda.

We disagree with the Administrator's decision to not place the upright MRI on the 2009 agenda. We ask that the HTCC independently place the upright MRI on the 2009 agenda for re-review.

We ask that time be set on your February 6, 2009, meeting agenda to address this request. Please let me know what further information you may require to make your assessment. In addition, we will make available, at the February 6, 2009, meeting, individuals to answer any questions that you may have regarding the technology and/or the new studies.

Washington State Health Care Authority
January 6, 2009
Page 2

Thank you for your consideration of this request. Please let me know if you have any questions or require further information.

Very truly yours,

LANE POWELL PC

A black rectangular redaction box covering the signature of Robert A. Battles.

Robert A. Battles

RAB/tlm
Enclosure

cc: Mr. Peter Solodko
122037.0002/34685.1

October 22, 2008

Washington State Health Care Authority
Health Technology Assessment Committee
P.O. Box 42712
676 Woodland Square Loop SE
Olympia, WA 98504-2712

Re: Re-Review of Upright MRI Technology

Dear HTA Committee:

Our office represents Capital Imaging, LLC.

We are aware of the Preliminary Recommendations for 2009 HTA Technology Topics dated October 15, 2008, posted on the Health Care Authority/HTA website that indicates under the Re-Review Recommendations section that “[a] PubMed literature scan was completed by the HTA clinical consultant . . . [that] did not reveal any significant new evidence that might lead to a different conclusion.” However, no mention of what information may have been reviewed or obtained and considered by the HTA.

We disagree the HTA’s recommendations and submit that additional significant information is and has been available during the re-review period. Attached is the following information that was not previously available during the review process and prior to the HTA Committee’s determination in May 2007.

1. *Supplement to The Spine Journal*, September/October 2007, Volume 7, Number 5S, pp. 38S-39S.
2. Letter from Jeffrey C. Wang, M.D., Chief, Orthopaedic Spine Service, UCLA Comprehensive Spine Center and Associate professor of Orthopaedic and Neurosurgery, UCLA School of Medicine, regarding indications for positional / kinetic MRI, dated August 6, 2007.
3. Abstract from the Proceedings of the NASS 22nd Annual Meeting / *The Spine Journal* 7 (2007) 1S-163S

Washington State Health Care Authority
October 22, 2008
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Capital Imaging therefore requests that the Upright MRI technology be placed on the 2009 HTA Technology Topics agenda. In the alternative, Capital Imaging requests the HTA perform a re-review of the Committee's determination of May 18, 2007, and consider the enclosed materials as part of its re-review determination process.

Very truly yours,

LANE POWELL PC



Robert A. Battles

RAB:ms
Enclosures
cc: Mr. Peter Solodko
122037.0002/34184.1

ATTACHMENT 1



SEPTEMBER/OCTOBER 2007
VOLUME 7, NUMBER 5S

SUPPLEMENT TO

THE SPINE JOURNAL

A Multidisciplinary Journal of Spinal Disorders



Proceedings of the 22nd
Annual Meeting of the
North American Spine Society

Austin, Texas
October 23-27, 2007

OFFICIAL JOURNAL OF THE
NORTH AMERICAN SPINE SOCIETY



The Spine Journal is indexed in *Index Medicus*

ISSN 1529-9430

SIG 1: Diagnostic Imaging: The Pros and Cons of Static, Dynamic, Upright and Supine Imaging. [Official Program Schedule, Wednesday, October 24, 2007]

Room 12B

Moderator: Christopher D. Chaput, MD

Spine surgery is changing from a discipline that uses primarily static imaging of the neuraxis to define pathology to one where dynamic studies are increasingly available. The need for evidence-based information on these imaging modalities is expected to increase as more options for nonfusion instrumentation become available to the spine surgeon. Discussion will center around currently available dynamic and static imaging and will seek to explore the relationship of such imaging to diagnosing and treating patients.

79: The Effect of Lumbar Flexion and Extension on the Central Canal with Dynamic MRI

Feng Wei, MD¹, Soon-Woo Hong, MD², Jun Zou, MD³, Benjamin Tow, MD², Masashi Miyazaki, MD², Yuichiro Morishita⁴, Ahmed Alanay, MD⁴, Jean-Jaques Abitbol, MD, FACS⁵, Jeffrey Wang, MD⁶; ¹LA, CA, USA; ²CA, USA; ³University of California Los Angeles, Los Angeles, CA, USA; ⁴University of California, Los Angeles, Los Angeles, CA, USA; ⁵Fukuoka, Fukuoka, Japan; ⁶San Diego, CA, USA

BACKGROUND CONTEXT: Lumbar central canal stenosis is defined as the reduction in the diameter of the spinal central canal, which causes neurogenic claudication and radicular leg pain. Previous myelography and in vitro study of cadaveric specimens showed that extension of the spine caused protrusion of the intervertebral disc, bulging of the ligamenta flava and spondylolisthesis, resulting in a narrowing of the canal. However, few noninvasive studies exist to show these results. Dynamic MRI studies can show with high precision the amount of change of the diameter of the spinal canal with flexion and extension of the spine.

PURPOSE: The purpose of this study was to define the diameter changes of the spinal canal at each level of the lumbar spine with dynamic MRI studies, to document the amount of change, and to see how progressive degeneration of the disc at the functional spinal unit will affect these values. **STUDY DESIGN/SETTING:** This was a retrospective study on patients who presented with low back pain and were examined by dynamic MRI to determine the effect of lumbar flexion and extension on spinal canal.

PATIENT SAMPLE: Lumbar MR images for 491 patients, including 192 male and 169 female, (15-85 years of age), with lower back pain, were obtained.

OUTCOME MEASURES: All radiological data on MRI was recorded on computer based measurement from MRI taken by flexion, neutral and extension.

METHODS: All patients were examined in sitting flexion 40 degree, upright, and extension 10 degree within a 0.5 T dynamic MRI scanner. Quantitative measurements of canal diameter in the sagittal midline in disc level were obtained for each position. Degeneration was graded according to the signal of the discs in T2 weighted images. Change ratios of the canal diameter from neutral position to flexion or extension were calculated to reflect the extent of change relative to the grade of degeneration.

RESULTS: Statistically significant differences in canal diameter were obtained between neutral and flexion position and between neutral and extension position for L2-3 to L5-S1 levels. Results showed that flexion increased the canal diameter and extension decreased the canal diameter. Change ratio of L4-5 was greatest in both flexion and extension. In flexion, the change ratio positively correlated with the degree of degeneration in L2-3 to L5-S1. In extension, the change ratio negatively correlated with the degree of degeneration in L3-4 only.

CONCLUSIONS: Dynamic MRI can demonstrate spinal canal diameter change in lumbar flexion and extension and also show the amount of change in the cross-sectional area with the highest accuracy. The spinal canal is widest in flexion and narrowest in extension. The relief of spinal stenosis in flexion is greater when the degree of degeneration is more severe. Furthermore, the less amount of degeneration, the greater the

change in extension of the canal diameter. This study is the first to fully define the amount of diameter change of the spinal canal with flexion and extension of the spine, quantify the change at each level, and demonstrate how these values change with the increasing amount of degenerative grade of the disc at the functional motion segment.

FDA DEVICE/DRUG STATUS: Dynamic MRI; Approved for this indication.

doi: 10.1016/j.spinee.2007.07.096

80: Positional MRI: A Valuable Tool in the Assessment of Cervical Disc Bulge

Payam Moazzaz, MD¹, Soon Woo Hong, MD¹, Masashi Miyazaki, MD¹, Mark Ashkan, BS¹, Jeffrey Wang, MD¹; ¹University of California, Los Angeles, Santa Monica, CA, USA

BACKGROUND CONTEXT: Positional MRI (pMRI) has recently been proposed as an alternative to conventional MRI techniques. pMRI offers the advantage of assessing cervical spine pathology in the neutral, flexion, and extension positions. pMRI also allows examination of the cervical spine in a more physiologic, weight-bearing position as compared to traditional supine MRI imaging. A recent review of the literature demonstrated no studies to-date that have investigated the amount of cervical disc bulge in the neutral, flexion, and extension positions.

PURPOSE: The purpose of this study was to determine if adding flexion and extension MRI data to traditional neutral views would be beneficial in the evaluation of cervical disc bulges.

STUDY DESIGN/SETTING: Patients with radicular cervical spine signs and symptoms underwent pMRI in neutral, flexion, and extension. The images were analyzed using novel computer measurement technology to objectively quantify the amount of disc bulge.

PATIENT SAMPLE: One hundred sixty-three patients with radicular cervical spine symptoms were included in the study. This represented 978 cervical discs in total. There were 69 males and 94 females. The mean age was 44.1 years (range 19-93).

OUTCOME MEASURES: Disc bulge was measured as the amount of extension of the disc beyond the intervertebral space. Discs with less than 2.0 mm disc bulge in the neutral position were selected and compared with their respective flexion and extension data.

METHODS: Disc bulge was measured using MRI Analyzer™ Version 3 (Traumatic Corporation: Bellflower, CA) anatomic software to objectively quantify the amount of disc bulge in millimeters. The statistical significance was calculated using the chi-square test.

RESULTS: The mean disc bulge was 1.96 mm in neutral, 1.86 mm in flexion and 1.93 mm in extension (n=978 discs). For discs with less than 2.0 mm disc bulge in neutral (n=539 discs), the results were as follows: 18.18% 2.0 mm bulge in flexion and 23.75% 2.0 mm bulge in extension (p=0.025). In addition, 2.41% 3.0 mm bulge in flexion and 3.34% 3.0 mm bulge in extension (p=0.36). Using 2.0 mm of disc bulge as a cut-off value, the false negative ratio for the neutral position alone compared to flexion and extension was 25.08%.

CONCLUSIONS: A significant increase in the degree of cervical disc bulge was found by examining flexion and extension views as compared to neutral views alone. This study also suggests that extension MRI views yield a higher detection rate of missed cervical disc bulges than flexion views. Flexion and extension MRI views provide valuable, added information when assessing patients for cervical disc bulge. This data suggests that positional MRI might be especially beneficial in patients with symptomatic radiculopathy and unimpressive static MRI studies.

FDA DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable device or drugs.

doi: 10.1016/j.spinee.2007.07.097

111. Kinematic Analysis of Relationship Between the Grade of Disc Degeneration and the Motion Unit in Cervical Spine

Masashi Miyazaki, MD¹, Soon Woo Hong, MD¹, Seung Hwan Yoon, MD¹, Jun Zou, MD¹, Benjamin Dwyer, MD¹, Ahmet Alanay, MD¹, J.J. Abitbol, MD, FACS¹, Jeffrey C. Wang, MD¹: ¹University of California, Los Angeles, Los Angeles, CA, USA

BACKGROUND CONTEXT: Many people suffer from cervical degenerative disease. The degree of degeneration of cervical spine has not been compared with the extent of cervical spine mobility. The effect of degeneration of the disc on the overall motion of the functional spinal unit is also not defined. Dynamic Motion MRI studies can demonstrate the mobility of each motion segment and define where the motion of the spine occurs, and it can relate it to the grade of degeneration.

PURPOSE: To define the relationship between the grade of disc degeneration and the motion unit in cervical spine and to elucidate how the role of each cervical spine unit for flexion-extension motion changes with degeneration with dynamic MRI.

STUDY DESIGN/SETTING: Prospective patients with neck pain were enrolled and obtained a dynamic flexion/extension MRI of the cervical spine.

PATIENT SAMPLE: 168 patients were permitted to enroll our study with symptomatic neck pain with/without radiculopathy or myelopathy.

OUTCOME MEASURES: All radiological data on MRI was recorded on computer based measurement from MRI taken by flexion, neutral and extension.

METHODS: MRI analyzer in true MRI which included 76 point marked in each image were undergone automatically all measurements and calculations with regard to translational motion and angular variation on each segment. According to grading system on the basis of the literature, two observers analyzing MRIs graded 5 (grade I to V) in each of intervertebral disc on the T2-weighted sagittal images.

RESULTS: On the each cervical unit, compare to more normal discs with Grade I and II mild degeneration, translational motion and angular variation increased for segments with discs with higher degenerative grades (Grade III and IV). However, the authors observed that the translational motion and angular variation of the segments decreased significantly in severe Grade V degeneration. For the Grade I and II segments, C4/5 and C5/6 units contributed the majority of the total angular mobility of the spine. For Grade III and IV degeneration, the segments of C3/4 and C6/7 units increased as well as C4/5 and C5/6 units. In Grade V, the roles of C4/5 and C5/6 units for total angular mobility decreased.

CONCLUSIONS: Following degeneration, the changes of translational motion and angular variation were observed. Namely, the authors demonstrated the changes that occur with progressive degeneration. The angular motion and translation moves from normal disc (Grade I and II) to a more unstable phase (Grade III and IV) to a more ankylosed stage with more stability (Grade V). We also demonstrate the contribution of different levels to overall motion that occurs with degeneration.

FDA DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable devices or drugs.

doi: 10.1016/j.spinee.2007.07.132

145. Missed Spondylolisthesis in Static MRIs but Found in Dynamic MRIs in the Patients with Low Back Pain

Soon-Woo Hong, MD¹, Ahmet Alanay, MD², Seung Hwan Yoon, MD¹, Masashi Miyazaki, MD¹, Jun Zou, MD¹, Mark Ashkan, BS³, Marlaine Chen¹, Jeffrey Wang, MD¹: ¹University of California, Los Angeles, Santa Monica, CA, USA; ²Hacettepe University, Ankara, Turkey; ³Albert Einstein College of Medicine, Bronx, NY, USA

BACKGROUND CONTEXT: Spondylolisthesis is known as one of results of instability. And the measurement has been established by using simple X-rays. But, X-rays should be taken several times for positional change and they make the patient exposed to much radiation hazard. Comparing X-ray, dynamic MRI can make exact sagittal images replacing true lateral view of X-rays during positional change. But, to date any quantitative report has not been done for detecting spondylolisthesis in flexion and extension MRIs while neutral MRIs show normal.

PURPOSE: To evaluate how many the dynamic MRI can detect the missed spondylolisthesis in static MRI.

STUDY DESIGN/SETTING: Our radiological study was processing on prospective, randomized methods in the patients who complained low back pain with/without radiating pain.

PATIENT SAMPLE: 510 patients who permitted to enroll our study in low back pain with/without radiculopathy.

OUTCOME MEASURES: All radiological data on MRI was recorded on computer based measurement from MRI taken by flexion, neutral and extension.

METHODS: 510 patients (186 females, 324 males, mean age 42.2 years, range 16-85 years) had taken dynamic MRIs for the study. Images were gotten from the positions of flexion 40 degrees, upright, and extension 10 degrees. MRI Analyzer in true MRI which included 67 points marked in each image has undergone automatically all measurement and calculation with regard to translation from L1-2 to L5-S1 by Meyerdinger's method. We decided a normal slip limit as the slip under 3 mm anteriorly and posteriorly at first, and then under 4 mm secondly. The number in which the neutral MRI showed normal but flexion or extension MRI showed over 3 mm or 4 mm, that is, missed spondylolisthesis was counted. Statistical analysis was performed using Chi-square test with significance set at $p < 0.05$.

RESULTS: In the case when spondylolisthesis meant more than 3 mm translation, the total count and percent of missed spondylolisthesis is 41 and 8.1% in flexion. For each level in flexion, L3-4 level was most commonly missed as 38.7% and L4-5 level was 35.1%, L2-3 level 30.8%, and L5-S1 level 4%. In extension view, the total count and percent was 18 and 3.9% which was smaller than in flexion ($p=0.005$). And for each level in extension, L2-3 level was 25%, L3-4 level 20.8%, L4-5 level 14%, and L5-S1 level 3.2%. When spondylolisthesis was decided as more than 4 mm translation, total count and percent of missed spondylolisthesis was 18 and 12.3% in flexion but it was not different statistically from the result of more than 3 mm translation ($p=0.148$). For each level in flexion, L3-4 level was most commonly missed as 53.8% and L2-3 level was 33.3%, L4-5 level 17.9%, and L5-S1 level 3.5%. In extension view, the total count and percent was 6 and 5% which was smaller than in flexion ($p=0.042$). And for each level in extension, L2-3 level was 33.3%, L3-4 level 25%, L4-5 level 4.2% and L5-S1 level 2.4%.

CONCLUSIONS: In the patients with back pain, missed spondylolisthesis in neutral MRIs but found in flexion MRIs is 18.1% for all the levels in the condition that spondylolisthesis is considered as more than 3 mm translation. And it is larger than in extension MRIs because flexion movement makes more anterior translation. The rate of newly found spondylolisthesis in flexion or extension MRIs with 3 mm criteria is not quite different from 4 mm criteria.

FDA DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable devices or drugs.

doi: 10.1016/j.spinee.2007.07.171

ATTACHMENT 2

UNIVERSITY OF CALIFORNIA, LOS ANGELES

UCLA

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SANTA BARBARA • SANTA CRUZ

UCLA/ORTHOPAEDIC HOSPITAL
DEPARTMENT OF ORTHOPAEDIC SURGERY
DAVID GEFFEN SCHOOL OF MEDICINE
1250 16TH STREET, 7TH FLOOR TOWER #145
SANTA MONICA, CA 90404
MC: 703646

August 6, 2007

Cervical Spine

Indications for Cervical positional / kinetic MRI (kMRI) as study of choice:

Note: ~~Indications and recommendations are based on our study of 1,000 patients having kinetic MRI studies demonstrating over 20% miss rates of instability, cervical stenosis, cervical disc herniation, cervical spondylolisthesis, and other missed pathologies.~~

1. Generalized cervical or neurological complaints (e.g., back pain or radiculopathy)
2. Patients with spondylolisthesis to characterize the amount of instability present.
3. Patients with C1-C2 instability to characterize the amount of spinal cord compression.
4. Patients with suspected spinal pathology after cervical trauma with or without evidence of abnormalities on standard studies to characterize the amount of instability and the injured structures.
5. Patients who are surgical candidates for cervical disc arthroplasty for pre-operative evaluation to confirm the absence of instability, facet pathology, or neuroforaminal narrowing.
6. Patients who are candidates for cervical fusion surgery with evidence of degenerative pathology to rule out adjacent level disease, instability, or stenosis.
7. Patients who are surgical candidates for posterior motion sparing devices (e.g., pedicle-based motion-allowing rods)

Relative indications:

1. Pre-operative evaluation for patients undergoing cervical decompressive surgery to help decide on the appropriate levels for decompression.
2. Pre-operative evaluation for patients undergoing cervical fusion surgery to help decide on the appropriate levels for fusion.
3. Pre-operative evaluation for patients undergoing cervical surgery to rule out adjacent segment problems, characterize the amount of instability present, and the expectations from the surgical procedure through the range of motion of the cervical spine.
4. Patients with rheumatoid arthritis to rule out atlanto-axial instability.

Thoracic Spine

Indications for Thoracic positional / kinetic MRI (kMRI):

1. Generalized thoracic or neurological complaints (e.g., back pain or radiculopathy).

11/01/2007 12:25 631-390-7756

FONAR CORP

PAGE 03

Lumbar Spine**Indications for Lumbar positional / kinetic MRI studies (kMRI):**

Note: These recommendations are based on our study of 1,000 patients having kinetic MRI studies demonstrating over 20% miss rates of instability, lumbar stenosis, lumbar disc herniations, lumbar spondylolisthesis, and other missed pathologies.

Indications for Lumbar kMRI studies:

1. Generalized lumbar or neurological complaints (e.g., back pain or radiculopathy)
2. Patients with spondylolisthesis to characterize the amount of instability present.
3. Patients who are surgical candidates for lumbar disc arthroplasty for pre-operative evaluation to confirm the absence of instability, facet pathology, or neuroforaminal narrowing.
4. Patients who are candidates for lumbar fusion surgery with evidence of degenerative pathology to rule out adjacent level disease, instability, or stenosis.
5. Patients with spinal stenosis who are surgical candidates for interspinous spacer (to confirm/predict the amount of decompression from device and to confirm that they are appropriate candidates)
6. Patients who are surgical candidates for posterior motion sparing devices (e.g., pedicle-based motion-allowing rods)

Relative indications:

1. Pre-operative evaluation for patients undergoing lumbar decompressive surgery to help decide on the appropriate levels for decompression.
2. Pre-operative evaluation for patients undergoing lumbar fusion surgery to help decide on the appropriate levels for fusion.
3. Pre-operative evaluation for patients undergoing lumbar surgery to rule out adjacent segment problems, characterize the amount of instability present, and the expectations from the surgical procedure through the range of motion of the lumbar spine.

Follow-Up Study

Note: Positional kMRI of the spine (C/T/L) as a follow-up study is recommended in cases where there is absence of symptoms correlated compressive pathology on standard recumbent MRI studies (i.e., if the treating physician believes that the standard recumbent MRI missed clinically suspected pathology).

If you have any further questions please do not hesitate to contact me.

Sincerely,



Jeffrey C. Wang, M.D.
 Chief, Orthopaedic Spine Service
 UCLA Comprehensive Spine Center
 Associate Professor of Orthopaedic and Neurosurgery
 UCLA School of Medicine
 1250 16th street, 7th tower, #745
 Santa Monica, CA 90404
 Tel: (310) 319-3334 or 319-3827, Fax: (310) 319-5055

ATTACHMENT 3

of HRQL include: SRS-22 and SF-12. Spearman's Rank Order Correlation was used to determine relationships between individual radiographic parameters and HRQL. Patients were then grouped into dichotomous deformity patterns including: High(III-V)/Low grade (I-II) by Mycroding Grade, kyphosis or lordosis at L5-S1, and high (>30 degrees) and low (<10 degrees) pelvic tilt. Dichotomous variables were analyzed using Student's t-test.

RESULTS: 37 adults (age 18-68) with spondyloarthrosis had complete radiographs and clinical data. There is a moderate correlation between C7 sagittal balance and appearance (r=0.7), and selfody (r=0.6) on the SRS-22 instrument. All other radiographic parameters had a low independent correlation with HRQL. Grouping patients by lordosis or kyphotic slip angle at L5-S1, adults with a neutral or kyphotic angle at L5-S1 had significantly more pain (p=0.01), functional limitations (p=0.02), and mental health compromise (p=0.01) than patients with a lordotic slip angle. Adults with a high pelvic tilt had significantly worse scores for appearance (0.03), pain (p=0.00), function (p=0.02), and physical component summary (0.05). Adults with a high grade osteoarthritis (III,IV) had more limitations in physical role (p=0.04) and mental health (p=0.02) than those with a low grade osteoarthritis.

CONCLUSIONS: Surgical strategies for the management of high-grade spondyloarthrosis remain variable. Reduction of high-grade spondyloarthrosis may restore lumbosacral and lumbopelvic alignment to the range of normal. The value of deformity reduction on improving outcomes has not been demonstrated. This study demonstrates that global sagittal balance is the only individual radiographic parameter with a moderate correlation with health status. Grouping patients into deformity patterns, segmental kyphosis at L5-S1, osteoarthritis greater than grade III, and pelvic tilt less than 30 degrees are significantly associated with a measurable compromise of health status. This data may support the role of deformity reduction in the management of spondyloarthrosis in the adult.

FDA DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable devices or drugs.

doi: 10.1016/j.spinee.2007.07.093

Thursday, October 25, 2007

4:15-5:03 PM

Concurrent Session 2: Diagnostics

78. Reference Data for Interpreting Interspinous Process Widening in Flexion/Extension X-rays Of The Cervical Spine
 Aaron Subanks, MD¹, John Hipp, PhD², Felag Ben-Galim, MD³, Charles Balmer, MD⁴; Houston, TX, USA

BACKGROUND CONTEXT: Lateral flexion and extension radiographs of the cervical spine are commonly used to evaluate injuries or disease that may not be apparent on static unstressed films. Computer assisted imaging techniques are now commonly used in the analysis of cervical motion, and reference data for interpreting intervertebral rotations and translations have been published. However, there are currently no clinically validated criteria for assessing interspinous process widening in flexion-extension studies of the cervical spine.

PURPOSE: The purpose of this study is to document normal interspinous widening in a cohort of asymptomatic adults, using previously validated tracking software.

STUDY DESIGN/SETTING: Prospective cervical flexion and extension radiographs were taken, the images tracked, and interspinous widening calculated for each cervical level.

PATIENT SAMPLE: 156 skeletally mature subjects were recruited to participate in the study. Patients were not recruited if they reported prior neck pain which necessitated a visit to a physician.

OUTCOME MEASURES: Cervical interspinous widening was defined by the distance between spinous process tips in full flexion minus their distance in full extension, divided by the width of the superior endplate of the C4 vertebra.

METHODS: Each full flexion and extension was captured with an all digital fluoroscopic imaging system (KIMAX, Medical Metrics, Inc, Houston, TX). The tracking and stabilization software (QMA, Medical Metrics) allows the specified vertebrae to be superimposed in flexion and extension. It thus permits easy visualization of motion between vertebrae. The software was then able to report the distance between spinous process tips in flexion and extension. This technique has been validated to measure intervertebral rotational motion with errors less than 0.5 deg and intervertebral translational motion with errors less than 0.5 mm.

RESULTS: Of the 156 asymptomatic subject entered into the study, 7 had images that could not be tracked, and not all levels could be analyzed due to problems visualizing the anatomy. The remaining 149 subjects provided 665 cervical levels for analysis. The mean, stdev, and the lower and upper limits of the 95% confidence interval for each cervical level are provided in Table #1. The lower cervical spine contributed the most to motion. A comparison of the motion at any given level to its adjacent levels shows maximally 50% more motion than its neighbor (Figure #1).

CONCLUSIONS: This data supports the general rule that interspinous widening by greater than 50% of the adjacent levels represents an abnormal finding and should raise clinical concern for disease or injury.

FDA DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable devices or drugs.

Level	Mean	StdDev	N	LL 95% CI	UL 95% CI
C1C2	29.71	16.83	140	-3.27	62.70
C2C3	34.18	13.45	149	7.82	60.54
C3C4	54.85	18.01	148	19.19	89.61
C4C5	62.27	20.67	148	21.98	102.59
C5C6	60.08	26.41	146	8.30	111.81
C6C7	63.72	27.43	137	-0.04	107.47

Table 1. Summary of Data

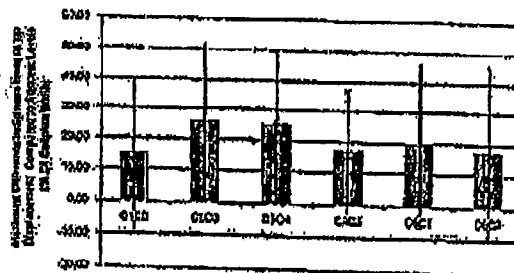


Figure 1. Mean maximum absolute difference and 95% CI between adjacent levels in spinous process tip displacement.

doi: 10.1016/j.spinee.2007.07.095

79. Effect of Cervical Flexion and Extension on the Cervical Interspinous Process

Feng Wei, MD¹, Soon-Woo Hong, MD², Jun Zou, MD³, Benjamin Tom, MD⁴, Masashi Miyazaki, MD⁵, Yutaka Morishita⁶, Ahmet Atasoglu, MD⁷, Jean-Jacques Abitbol, MD, FACS⁸, Jeffrey Wang, MD⁹; ¹LA, CA, USA; ²CA, USA; ³University of California Los Angeles, Los Angeles, CA, USA; ⁴University of California, Los Angeles, Los Angeles, CA, USA; ⁵Fukuoka, Fukuoka, Japan; ⁶San Diego, CA, USA

BACKGROUND CONTEXT: The reduction in the diameter of the cervical interspinous process during flexion and extension is a well-known phenomenon. However, the reduction in the diameter of the cervical interspinous process during flexion and extension is not well understood. This study aims to investigate the effect of cervical flexion and extension on the cervical interspinous process.

neurogenic claudication and radicular leg pain. Previous myelography and in vitro study of cadaveric specimens showed that extension of the spine caused protrusion of the intervertebral disc, bulging of the ligamentum flavum and spondyloarthrosis, resulting in a narrowing of the canal. However, few noninvasive studies exist to show these results. Dynamic MRI studies can show with high precision the amount of change of the diameter of the spinal canal with flexion and extension of the spine.

PURPOSE: The purpose of this study was to define the diameter changes of the spinal canal at each level of the lumbar spine with dynamic MRI studies, to document the amount of change, and to see how progressive degeneration of the disc at the functional spinal unit will affect these values.

STUDY DESIGN/SETTING: This was a retrospective study on patients who presented with low back pain and were examined by dynamic MRI to determine the effect of lumbar flexion and extension on spinal canal.

PATIENT SAMPLE: Lumbar MR images for 461 patients, including 192 male and 169 female, (15-85 years of age), with lower back pain, were obtained.

OUTCOME MEASURES: All radiological data on MRI was recorded on computer based measurement from MRI taken by flexion, neutral and extension.

METHODS: All patients were examined in sitting flexion 40 degree, upright, and extension 10 degree within a 0.5 T dynamic MRI scanner. Quantitative measurements of canal diameter in the sagittal midline in disc level were obtained for each position. Degeneration was graded according to the signal of the discs in T2 weighted images. Change ratios of the canal diameter from neutral position to flexion or extension were calculated to reflect the extent of change relative to the grade of degeneration.

RESULTS: Statistically significant differences in canal diameter were obtained between neutral and flexion position and between neutral and extension position for L2-3 to L5-S1 levels. Results showed that flexion increased the canal diameter and extension decreased the canal diameter. Change ratio of L4-5 was greatest in both flexion and extension. In flexion, the change ratio positively correlated with the degree of degeneration in L2-3 to L5-S1. In extension, the change ratio negatively correlated with the degree of degeneration in L2-3 to L5-S1 only.

CONCLUSIONS: Dynamic MRI can demonstrate spinal canal diameter changes in lumbar flexion and extension MRI also show the amount of change in the functional spinal unit with the highest accuracy. The spinal canal diameter in flexion and extension. The ratio of spinal diameter in flexion or extension when the degree of degeneration is greater than 1. Furthermore, the less amount of degeneration, the greater the change in diameter of the spinal canal. This study is the first to fully define the amount of diameter change of the spinal canal with flexion and extension of the spine, quantify the change at each level, and demonstrate how these values change with the increasing amount of degenerative disc disease at the functional motion segment.

DISC DEVICE/DRUG STATUS: Dynamic MRI: Approved for this indication.

doi: 10.1016/j.spinee.2007.07.096

POSITIONAL MRI: A Valuable Tool in the Assessment of Cervical Disc Disease

Pooyon Mouazzes, MD¹, Soon Woo Hong, MD², Marashi Miyazaki, MD³, Mark Athkan, DS⁴, Jeffrey Wang, MD⁵; ¹University of California, Los Angeles, Santa Monica, CA, USA

BACKGROUND CONTEXT: Positional MRI (pMRI) has recently been proposed as an alternative to conventional MRI techniques. pMRI offers the advantages of assessing cervical spine pathology in the neutral, flexion, and extension positions. pMRI also allows examination of the cervical spine in a more physiologic, weight-bearing position as compared to traditional supine MRI imaging. A recent review of the literature demonstrated

no studies to-date that have investigated the amount of cervical disc bulge in the neutral, flexion, and extension positions.

PURPOSE: The purpose of this study was to determine if adding flexion and extension MRI data to traditional neutral views would be beneficial in the evaluation of cervical disc bulges.

STUDY DESIGN/SETTING: Patients with radicular cervical spine signs and symptoms underwent pMRI in neutral, flexion, and extension. The images were analyzed using novel computer measurement technology to objectively quantify the amount of disc bulge.

PATIENT SAMPLE: One hundred sixty-three patients with radicular cervical spine symptoms were included in the study. This represented 274 cervical discs in total. There were 69 males and 94 females. The mean age was 54 years (range 19-89).

OUTCOME MEASURES: Disc bulge was measured as the amount of extension of the disc beyond the intervertebral space. Discs with less than 2.0 mm disc bulge in the neutral position were selected and compared with their respective flexion and extension data.

METHODS: Disc bulge was measured using MRI Analyzer™ Version 3 (Transcetric Corporation, Bellflower, CA) anatomy software to objectively quantify the amount of disc bulge in millimeters. The statistical significance was calculated using the chi-square test.

RESULTS: The mean disc bulge was 1.96 mm in neutral, 1.86 mm in flexion, and 1.93 mm in extension (n=978 discs). For discs with less than 2.0 mm disc bulge in neutral (n=339 discs), the results were as follows: 18.18% 2.0 mm bulge in flexion and 23.75% 2.0 mm bulge in extension (p=0.025). In addition, 2.41% 3.0 mm bulge in flexion and 3.3% 3.0 mm bulge in extension (p=0.36). Using 2.0 mm of disc bulge as a cut-off value, the false negative ratio for the neutral position alone compared to flexion and extension was 23.04%.

CONCLUSIONS: Significant differences in the degree of cervical disc bulge was found by examining flexion and extension views as compared to neutral views alone. This study also suggests that extension MRI views yields higher detection rate of increased cervical disc bulges than flexion views. Flexion and extension MRI views provide valuable added information when assessing the extent of cervical disc bulge. This data suggests that positional MRI might be especially beneficial in patients with asymptomatic radiologically and/or conservatively stable MRI studies.

DISC DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable devices or drugs.

doi: 10.1016/j.spinee.2007.07.097

SL FAD versus Provocative Discography: Comparative Results and Postoperative Clinical Outcomes

Todd Alamin, MD¹, VJay Arora², Eugene Carragee, MD³; ¹Stanford, CA, USA; ²IL, USA; ³Stanford University, Stanford, CA, USA

BACKGROUND CONTEXT: To address problems with the diagnosis of discogenic low back pain, we have designed a new test, the Functional Anesthetic Discogram. This test involves the performance of a standard provocative discogram, followed by the placement of a catheter into the putative disc(s) found to be concordantly painful on injection. The patient then assumes a position that would ordinarily cause him or her pain. Anesthetic is then delivered into the disc, and pain relief in that position is recorded.

PURPOSE: We performed this study to determine the results of the Functional Anesthetic Discogram in 31 patients with chronic low back pain, and to compare them with the results of standard provocative discography in this group of patients.

STUDY DESIGN/SETTING: This study was an IRB-approved, prospective clinical trial of a novel technique performed in a university practice.

PATIENT SAMPLE: 41 patients (21F, 20M) with chronic low back pain referred on for surgical consultation.

OUTCOME MEASURES: Pre-study VAS, Oswestry, and DRAM scales were recorded; during the test, VAS scales, pain concordancy, and prismatization data were recorded. Post-operative VAS and Oswestry scores along

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Proceedings of the NASS 22nd Annual Meeting / The Spine Journal 7 (2007) 15-1635

non smokers. There was a strong trend toward lower fusion rates at six months for multilevel vs. single-level patients (64.5% versus 84.0%), but this difference did not quite reach statistical significance ($P=0.0623$).

CONCLUSIONS: In this study, the only statistically significant factor correlating with nonunion following ACDF with allograft and cervical plating was age. Although there was a strong trend toward lower fusion rates for multilevel cases at six months postoperatively, this difference did not reach statistical significance. Smoking did not appear to be a significant risk factor for nonunion.

FDA DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable devices or drugs.

doi: 10.1016/j.spinee.2007.07.130

110. Prospective Study of Serum Metal Ion Levels in Patients with Stainless Steel Metal-on-metal Cervical Disc Replacements
Vincem Troynette, MD¹, J. Kenneth Burkus, MD², Matthew P. Gornet, MD³, Joshua J. Jacobs, MD⁴, Anastasia K. Skipor, MS⁵, Keith Katsonec, DO⁶, Iowa Clay, IA, USA; ¹The Haglund Clinic, Columbus, GA, USA; ²The Orthopedic Center of St. Louis, St. Louis, MO, USA; ³Rush University Medical Center Chicago, IL, USA; ⁴Bloomington, IL, USA

BACKGROUND CONTEXT: Total disc replacement is a recent alternative treatment for degenerative disc disease. Corrosion of metallic wear particles can lead to increased metal ion release in the body.

PURPOSE: We measured the serum chromium (Cr) and nickel (Ni) levels in patients who were implanted with stainless steel metal-on-metal cervical disc replacement devices.

STUDY DESIGN/SETTING: Prospective study of serum levels in patients implanted with the PRESTIGETM Cervical Disc.

PATIENT SAMPLE: In this prospective study, 25 patients with degenerative disc disease were treated with disc replacement using an artificial cervical disc containing a metal-on-metal, 316L stainless steel (ASTM F138; 18% Cr, 14% Ni) ball-in-rough articulation.

OUTCOME MEASURES: Serum was assayed for Cr and Ni using a high-resolution inductively-coupled plasma-mass spectrometry (Element, Finnigan MAT, Bremen, Germany). The detection limits were 0.015 ng/mL for Cr and 0.17 ng/mL for Ni. Values below the detection limits were assigned a value of half the detection limit. Longitudinal statistical comparisons were made using the Friedman test.

METHODS: Serum samples were collected preoperatively (n=25 patients) and at three (n=25) and at six (n=17) months postoperatively.

RESULTS: The median Cr levels were 0.074 ng/mL at pre-op, 0.11 ng/mL at three months and 0.12 ng/mL at six months. The difference was statistically significant ($p<0.01$) between serum Cr levels at both three- and six-month time periods compared with pre-op levels. The median Ni levels were 0.085, 0.18, and 0.21 ng/mL at pre-op, three months, and six months, respectively. The difference was statistically significant ($p=0.035$) only between six-month and pre-op levels. Generally, the values for Ni were quite low with many samples having levels below the detection limit. It is interesting to note that the median serum Cr values were an order of magnitude lower than values seen in a group of cobalt-alloy (ASTM F75; 30% Cr) metal-on-metal hip surface replacements and total hip replacements at comparable time intervals [1]. Additionally, the serum Ni and Cr levels were an order of magnitude lower than those reported for posterior spinal arthrodesis with stainless steel instrumentation at comparable time intervals [2].

CONCLUSIONS: Short-term metal levels were an order of magnitude lower than those observed at similar time points in stainless steel posterior spinal instrumentation and cobalt-alloy metal-on-metal hips.

FDA DEVICE/DRUG STATUS: PRESTIGETM Cervical Disc; Investigational/Not approved.

doi: 10.1016/j.spinee.2007.07.131

111. Kinematic Analysis of Relationship Between the Grade of Disc Degeneration and the Motion Unit in Cervical Spine
Masami Miyazaki, MD¹, Soon Woo Hong, MD², Seung Hwan Yoon, MD³, Jun Zou, MD⁴, Benjamin Tam, MD⁵, Ajmer Alawneh, MD⁶, J.J. Abitbol, MD, FACS⁷, Jeffrey C. Wang, MD⁸; ¹University of California, Los Angeles, Los Angeles, CA, USA

BACKGROUND CONTEXT: Many people suffer from cervical degenerative disease. The degree of degeneration of cervical spine has not been compared with the extent of cervical spine mobility. The effect of degeneration of the disc on the overall motion of the functional spinal unit is also not defined. Dynamic Motion MRI studies can demonstrate the mobility of each motion segment and define where the motion of the spine occurs, and it can relate it to the grade of degeneration.

PURPOSE: To define the relationship between the grade of disc degeneration and the motion unit in cervical spine and to elucidate how the role of each cervical spine unit for flexion-extension motion changes with degeneration with dynamic MRI.

STUDY DESIGN/SETTING: Prospective patients with neck pain were enrolled and obtained a dynamic flexion/extension MRI of the cervical spine.

PATIENT SAMPLE: 168 patients were permitted to enroll our study with symptomatic neck pain with/without radiculopathy or myelopathy.

OUTCOME MEASURES: All radiological data on MRI was recorded on computer based measurement from MRI taken by flexion, neutral and extension. **METHODS:** MRI analyzer in true MRI which included 76 points marked in each image were undergone automatically all measurements and calculations with regard to translational motion and angular variation on each segment. According to grading system on the basis of the literature, two observers analyzing MRIs graded 3 (grade I to V) in each of intervertebral disc on the T2-weighted sagittal images.

RESULTS: On the each cervical unit, compare to more normal discs with Grade I and II mild degeneration, translational motion and angular variation increased for segments with discs with higher degenerative grades (Grade III and IV). However, the authors observed that the translational motion and angular variation of the segments decreased significantly in severe Grade V degeneration. For the Grade I and II segments, C4/5 and C5/6 units contributed the majority of the total angular mobility of the spine. For Grade III and IV degeneration, the segments of C3/4 and C6/7 units increased as well as C4/5 and C5/6 units. In Grade V, the roles of C4/5 and C5/6 units for total angular mobility decreased.

CONCLUSIONS: Following degeneration, the changes of translational motion and angular variation were observed. Namely, the authors demonstrated the changes that occur with progressive degeneration. The angular motion and translation moves from normal disc (Grade I and II) to a more unstable phase (Grade III and IV) to a more ankylosed stage with more stability (Grade V). We also demonstrate the contribution of different levels in overall motion that occurs with degeneration.

FDA DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable devices or drugs.

doi: 10.1016/j.spinee.2007.07.132

112. Does Bilateral Foraminotomy Eliminate C5 Palsy after Open-door Cervical Laminoplasty?

Gabriel Liu, MChB, MSc¹, Jin Sup Yoon, MD, PhD², Hong Xing Sun, MD, PhD³, Torphong Bunnaprasart, K. Daniel Riew, MD⁴; ¹Washington University School of Medicine, St. Louis, MO, USA; ²Washington University in St. Louis, St. Louis, MO, USA; ³MO, USA

BACKGROUND CONTEXT: C5 palsy is a well-recognized complication known to occur after cervical laminoplasty. Incidence of C5 palsy after laminoplasty without concurrent nerve root decompression has been reported to be between 5 to 17%. While bilateral C4-5 foraminotomy performed at the time of laminoplasty has been proposed to prevent such complication, there is little data published to validate its success among North American patients.

PURPOSE: The purpose of this study was to compare the safety and accuracy of pedicle screw placement in the thoracic spine using the free-hand anatomic technique with and without the knowledge of pre-op CT scan parameters.

STUDY DESIGN/SETTING: This study is a retrospective, randomized radiographic review of 22 patients.

PATIENT SAMPLE: 22 patients undergoing spinal deformity surgery were randomized into two groups. The average age was 14.6 years (10-18 years). All of the patients had idiopathic scoliosis, except one who had Scheuermann's Kyphosis.

OUTCOME MEASURES: Post-operative CT scans were obtained and used to assess pedicle screw placement. Pedicle screw cortical perforation was evaluated and described as projecting medially into the lateral recess, anteriorly or anterior-laterally without evidence of soft tissue impingement, and into the costovertebral junction.

METHODS: 22 patients undergoing spine deformity surgery were randomized into two groups. Group A patients either did not undergo pre-operative CT scans or the operative surgeon was blinded to CT. Group B patients had pre-op CT scans, the parameters of which the surgeon was made aware. Post-operative CT scans were obtained in all of these patients and used to evaluate screw placement.

RESULTS: The average age was 14.6 years (10-18 years). All of the patients had idiopathic scoliosis, except one in Group B who had Scheuermann's Kyphosis. The average Cobb angle was 50.3 (40-77 degrees). A total of 369 pedicle screws were placed. In group A, 18 screws (12.5%) were malpositioned out of a total of 164 placed; to group B, 31 (15.4%) were malpositioned out of 201 screws placed. Evaluation of preoperative CT scan did not significantly effect the percentage of screws that had some breaching of the cortex. The vast majority of breaches were in the costovertebral junction.

CONCLUSIONS: In experienced hands, there is not a significant difference in the incidence of pedicle screw malpositioning based on the ability to perform preoperative evaluations of CT scan-based pedicle parameters. With rigorous free hand anatomic technique, safe placement of pedicle screws is possible and can be done safely without the reliance on routine preoperative CT. This can decrease a patient's total radiation exposure over the course of treatment of their spinal deformity.

FDA DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable devices or drugs.

doi: 10.1016/j.spinee.2007.07.169

144. Ability of Magnetic Resonance Imaging to Detect Facet Arthrosis in the Cervical Spine

Ronald A. Lafosse, MD¹, Kathryn Keeler MD², Yrphong Banmangprern, MD³, K. Daniel Riew, MD¹; ¹Washington, DC, USA; ²Washington University in St. Louis, MO, USA; ³Washington University School of Medicine, St. Louis, MO, USA

BACKGROUND CONTEXT: While preoperative MRIs are considered to be standard of care prior to most cervical arthrodeses, CTs are usually not felt to be necessary. However, in the pre-operative work-up for an arthroplasty, most protocols require a CT to determine if facet arthrosis, a contraindication to arthroplasty, is present. As MRIs have improved in image quality, it has become possible to detect facet arthrosis in many cases.

PURPOSE: To determine if facet arthrosis can be detected reliably enough by MRI to obviate the need for a CT.

STUDY DESIGN/SETTING: Clinical radiographic study.

PATIENT SAMPLE: 23 inconspicuous patients.

OUTCOME MEASURES: Computed tomography scans were considered to be definitive for facet arthrosis and graded 0=normal; 1=cystic &/or sclerosis; 2=hyperostophy; 3=ankylosis. Since grades 1-3 are contraindicated in arthroplasty, the MRI was simply read as normal or abnormal for facet arthrosis.

METHODS: Three spine surgeons evaluated CTs and MRIs from 23 patients, obtained within 30 days of each other, on three separate occasions. All CT scans were obtained from the same state-of-the-art scanners, MRIs were from the same 1.5T machines. A total of 594 facets were evaluated.

RESULTS: 256 facets were normal on CT and of those, 163 (63.7%) were also interpreted to be normal on MRI, indicating moderate concordance ($\kappa=0.52$). However, this still meant that the MRI was read as having facet arthrosis in 93/256 cases (36.3%), where there was none. When facet arthrosis was present on CT, it was misread as being normal on MR 21.6% of the time. MRI inter/intra-reliability demonstrate poor to slight agreement ($\kappa=0.19-0.41$).

CONCLUSIONS: We found that MRIs were unable to accurately determine the presence of facet arthrosis in a substantial percentage of cases. Over 36% of normal facets were read as being abnormal and over 21% of abnormal facets were read as being normal. Despite the added radiation and expense, CT remains the gold standard for diagnosing facet arthrosis and is required pre-operatively for cervical arthroplasty.

FDA DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable devices or drugs.

doi: 10.1016/j.spinee.2007.07.170

145. Dynamic Spondylolisthesis in Static MRIs but Normal in Dynamic MRI in the Patients with Low Back Pain

Song Woo Hong, MD¹, Ahmet Alanay, MD², Seung Hwan Yoon, MD³, Masahito Miyazaki, MD⁴, Jun Zou, MD⁵, Mark Ashkan, BS⁶, Marianne Chen⁷, Jeffrey Wang, MD⁸; ¹University of California, Los Angeles, Santa Monica, CA, USA; ²Hacettepe University, Ankara, Turkey; ³Albert Einstein College of Medicine, Bronx, NY, USA

BACKGROUND CONTEXT: Spondylolisthesis is known as one of the causes of instability. And the measurement has been established by using simple X-rays. But, X-rays should be taken several times for positional change and they make the patient exposed to much radiation hazard. Comparing X-ray, dynamic MRI can make exact sagittal images replacing true lateral view of X-rays during positional change. But, to date any quantitative report has not been done for detecting spondylolisthesis in flexion and extension MRIs while neutral MRIs show normal.

PURPOSE: To evaluate how many the dynamic MRI can detect the missed spondylolisthesis in static MRI.

STUDY DESIGN/SETTING: One radiological study was proceeding on prospective, randomized methods in the patients who complained low back pain with/without radiating pain.

PATIENT SAMPLE: 510 patients who permitted to enroll our study in low back pain with/without radiculopathy.

OUTCOME MEASURES: All radiological data on MRI was recorded on computer based measurement from MRI taken by flexion, neutral and extension.

METHODS: 510 patients (185 females, 324 males, mean age 42.2 years, range 16-85 years) had taken dynamic MRIs for the study. Images were gotten from the positions of flexion 40 degrees, upright, and extension 10 degrees. MRI Analyzer in true MRI which included 67 points marked in each image has undergone automatically all measurement and calculation with regard to translation from L1-2 to L5-S1 by Merycoring's method. We decided a normal slip limit as the slip under 3 mm anteriorly and posteriorly at first, and then under 4 mm secondly. The number to which the neutral MRI showed normal but flexion or extension MRI showed over 3 mm or 4 mm, that is, missed spondylolisthesis was counted. Statistical analysis was performed using Chi-square test with significance set at $p < 0.05$.

CONCLUSIONS: Missed spondylolisthesis was detected in dynamic MRI in the patients with low back pain.

41 and 18.3% in flexion. For each level in flexion, L3-4 level was most commonly missed at 38.7% and L4-5 level was 35.1%, L2-3 level 30.8%, and L5-S1 level 4%. In extension view, the total count and percent was 18 and 8.9% which was smaller than in flexion ($p=0.005$). And for each level in extension, L2-3 level was 25%, L3-4 level 20.8%, L4-5 level 14%, and L5-S1 level 3.2%. When spondylolithesis was defined as more than 4 mm translation, total count and percent of missed spondylolithesis was 18 and 12.3% in flexion but it was not different statistically from the result of more than 3 mm translation ($p=0.148$). For each level in flexion, L3-4 level was most commonly missed at 33.8% and L2-3 level was 33.3%, L4-5 level 17.9%, and L5-S1 level 3.5%. In extension view, the total count and percent was 6 and 3% which was smaller than in flexion ($p=0.042$). And for each level in extension, L2-3 level was 33.3%, L3-4 level 25%, L4-5 level 4.2% and L5-S1 level 2.4%.

CONCLUSIONS: In the patients with back pain, missed spondylolithesis in flexion MRI is more in flexion MRI than in extension MRI. At the levels in the condition that spondylolithesis is considered as more than 3 mm translation, more than 10% more than in extension MRI. Extension movement makes more missed translation. The rate of newly found spondylolithesis in flexion or extension MRI with 3 mm criteria is not quite different from 4 mm criteria.

FDA DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable devices or drugs.

doi: 10.1016/j.spinee.2007.07.171

Friday, October 26, 2007

4:16-5:16 PM

Special Interest Poster Presentation 3:
Lumbar - Non-fusion

146. Indirect Decompression (X-Stop) versus Conventional Decompressive Surgery for Lumbar Spinal Canal Stenosis - A Prospective Randomized Trial

Björn Strömquist, MD, PhD¹, Svante Berg, MD², Paul Gerden, MD, PhD³, Ragnar Johansson, MD, PhD⁴, Tage Sahström⁵, Tyscho Tullberg⁶,
¹Lund, Sweden; ²Sweden; ³Lund University Hospital, Malmö, Sweden;
⁴Stockholm Spine Center, Uppsala, Sweden

BACKGROUND CONTEXT: Although generally successful, decompressive surgery for lumbar spinal canal stenosis has its complications and requires hospitalization and rehabilitation. Zucherman et al have demonstrated X-Stop patients to fare better than patients given conservative treatment in an RCT.

PURPOSE: To compare the outcomes in terms of function, quality of life and re-operations after indirect decompression versus conventional decompression for LSC.

STUDY DESIGN/SETTING: Prospective randomized study including patients with central spinal stenosis according to MRI or CT, refractory to conservative treatment and accepting participation in an RCT. Outcome at 6, 12 and 24 months.

PATIENT SAMPLE: 50 patients in each group using randomization by envelope. 34 males and 46 females, mean age 70 (43-89) years. Surgical treatment at three spine centers in Sweden.

OUTCOME MEASURES: Function and satisfaction according to the Zurich Spinal Stenosis Questionnaire, quality of life according to SF-36 and incidence of repeat operations as well as complications. Pain on the VAS scale.

METHODS: After completing preoperative data and in absence of exclusion criteria, patient randomized to either X-Stop treatment under

local anesthesia or decompressive surgery in general anesthesia on 1 or 2 levels.

RESULTS: Follow-up inclusion according to criteria is complete. Two cases of spinous process fractures have been noted in the X-Stop group and 11 cases were re-operated in the X-Stop group and 3 cases in the decompressive group. Follow-up to date demonstrates the patients at 6 and 24 months having similar outcome as regards the SF-36 and the ZSQ and both groups are significantly improved compared with baseline.

CONCLUSIONS: Preliminary figures demonstrate that, when successful, X-Stop decompressive surgery may give similar results as decompressive surgery in terms of function and quality of life. An increased rate of secondary surgery is obvious and will be analyzed regarding cause when the follow-up is complete.

FDA DEVICE/DRUG STATUS: X-Stop: Approved for this indication.

doi: 10.1016/j.spinee.2007.07.173

147. Intervertebral Disc Transplantation: A New Dimension in the Treatment of Degenerative Spinal Disease
Di-ke Ren, MD¹, Qing He², Xu Ding³, Li Hou¹, Jy Li¹, Keith De Luk¹,
¹Beijing, China; ²Department of Orthopaedic Surgery (The Navy General Hospital, Beijing, China); ³Department of Orthopaedics & Traumatology, The University of Hong Kong, Hong Kong, China

BACKGROUND CONTEXT: Spinal fusion is a well recognized treatment for the degenerated disc disease. However, one complication is accelerated adjacent segment degeneration. Artificial disc replacements have been developed but results are variable. The authors have previously reported success using intervertebral disc autografts, fresh allografts, and fresh frozen allografts as a non-fusion strategy in a primate model.

PURPOSE: To review the process of development of the concept of intervertebral disc allograft transplantation from primate experiments to a pilot human trial. To determine the feasibility and long term clinical results of this innovative treatment option in the human.

STUDY DESIGN/SETTING: A prospective, non-blinded study of outcomes in patients who received a fresh-frozen allograft intervertebral disc transplantation in the cervical spine.

PATIENT SAMPLE: Five patients, 4 males and 1 female, average age 47 years.

OUTCOME MEASURES: JOA scores and VAS scores were used to evaluate neuro-function. Serial MRI, static and dynamic radiographs were used to monitor the status of the grafts.

METHODS: All patients with cervical disc herniation underwent anterior disc excision and transplantation of a fresh-frozen endplate-disc-endplate composite disc allograft obtained from healthy donors. No internal fixation or perioperative immunosuppressant was used. The mean follow up period was 5 years and 3 months.

RESULTS: The average operating time was 1.8 hours and blood loss was 62 ml. At a minimum follow up of 5 years, all patients had improvement of the preoperative myelopathic or radiculopathic symptoms. Good union between the recipient bone and the graft endplates were seen after two months with no graft migration or subsidence. No radiological suggestion of immune-reaction was found. There was reduction of the disc height at the early postoperative period and mild degenerative changes at the final follow up.

However, all except one of the transplanted discs showed preservation of mobility without osteolysis in the flexion-extension radiographs at the final follow up. One patient needed an additional posterior foraminotomy for recurrent radiculopathy. This argument eventually resulted in auto-fusion. MRI at the final follow up showed preservation of hydration in at least 2 of the discs.

CONCLUSIONS: The mobility and stability of the spinal segment were preserved. Fresh-frozen allografts intervertebral disc transplantation has been successfully performed in a pilot human series without immunologic

OFFICIAL PROGRAM SCHEDULE

5:25-6:25 p.m.

Nursing Track SIG: Tissue Banking

Room 12B

Moderator: Beverly Perfituo, RN, BSN

This session focuses on bone graft physiology, allograft procurement and The Joint Commission's requirements.

Upon completion of this session, participants should be able to:

- Review bone graft physiology.
- Define allograft procurement methods.
- Identify The Joint Commission's requirements for handling of tissue.
- Discuss the hospital's required documentation for allograft use.

PA/NP Track SIG: Discussion of the Day's Educational Offerings

Room 16A

Moderators:

Ian W. Marks, MSc, PA-C

James Brezina, MD

Followed by:

6:30-8:00 p.m.

PA/NP/Surgeon Reception

Ballroom D Foyer

Rehabilitation Professional SIG: Where Are We as Peroperative Providers vs. Nonoperative Care Providers?

Room 18B

Moderators:

Michael L. Reed, DPT, OCS

Christopher J. Standaert, MD

Kenneth S. Yonemura, MD

Symposium SIG: The New Performance Measurement Programs: Your Care will be Assessed (See symposium description on page 38)

Room 15

Moderator: David A. Wong, MD, MSc, FRCS(C)

Symposium SIG: Treatment of the Symptomatic Lumbar Degenerative Disc Disease: Repair, Regenerate and Rehabilitate (See symposium description on page 41)

Room 17

Moderator: J. Kenneth Burkus, MD

SIG 1: Diagnostic Imaging: The Pros and Cons of Static, Dynamic, Upright and Supine Imaging

Room 12B

Moderator: Christopher D. Chaput, MD

Spine surgery is changing from a discipline that uses primarily static imaging of the neuraxis to define pathology to one where dynamic studies are increasingly available. The need for evidence-based information on these imaging modalities is expected to increase as more options for nonfusion instrumentation become available to the spine surgeon. Discussion will center around currently available dynamic and static imaging and will seek to explore the relationship of such imaging to diagnosing and treating patients.

SIG 2: Why Worry about Conflict of Interest?

Room 16B

Moderator: Wilton Bunch, MD

The term "conflict-of-interest" is being used in multiple medical settings and is discovered or implied somewhere nearly every day. It is easy to become overly saturated and ignore the issue. But, the issue is very real. This SIG discusses why it is important for every physician to be aware of and understand real and potential conflicts-of-interest.

5:25-6:25 p.m.

SIGP 1: Biologics

Room 12A

Moderator: Louis Jenis, MD

5:25-5:30 p.m.

26. Increased Expressions of Nerve Growth Factor and its Tropomyosin-related Kinase A Receptor: A Potential Mechanism for Development of Chordoma

Jong-Beom Park, MD, Uijongbu-si, South Korea; Choon-Ki Lee, MD, Seoul, South Korea

FDA DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable devices or drugs.

5:31-5:36 p.m.

27. Effect of In Vivo Sustained Release of Growth Factors on Degenerated Discs using a Rat Model

Scott Wingenter, MD, *James Woodall, Jr, MD, Michelle Tuod, PhD, Ashraf Ragab, MD, Ham Benghuzzi, PhD, Jackson, MS, USA

FDA DEVICE/DRUG STATUS: This abstract does not discuss or include any applicable devices or drugs.

*Denotes presenter if not first author listed.

Wednesday,
 October 24

**Health Technology Clinical Committee
Findings and Coverage Decision**

Topic: Coronary Computed Tomographic Angiography
Meeting Date: November 14, 2008
Final Adoption:

Number and Coverage Topic

20081114A – Coronary Computed Tomographic Angiography for detection of Coronary Artery Disease.

HTCC Coverage Determination

Coronary Computed Tomographic Angiography (CCTA) is **covered benefits with conditions** consistent with the criteria identified in the reimbursement determination.

HTCC Reimbursement Determination

❖ **Limitations of Coverage**

- 1) Patients with low to intermediate risk of coronary artery disease;
- 2) For investigation of acute chest pain in an emergency department or hospital setting; and
- 3) Using Computed Tomography machines with 64-slice or better capability.

❖ **Non-Covered Indicators**

Patients who are asymptomatic or at high risk of coronary artery disease;
 CCTA used for coronary artery disease investigation outside of the emergency department or hospital setting; and
 CT scanners that use lower than 64- slice technology.

❖ **Agency Contact Information**

Agency	Contact Phone Number
Labor and Industries	1-800-547-8367
Uniform Medical Plan	1-800-762-6004
Health and Recovery Services Administration	1-800-562-3022

Computed Tomographic Angiography Background

The Computed Tomographic Angiography topic was selected and published in August 2007 to undergo an evidence review process. Heart disease is the leading cause of death and disability in the US: with 700,000 deaths. The most common heart disease in the US is coronary artery disease (CAD), which can lead to heart attack. CAD is a narrowing of one or more coronary arteries that result in an insufficient supply of oxygen to the heart muscle and is a leading cause of death in the US and developed countries. CAD may be asymptomatic or lead to chest pain (angina), heart attack, myocardial infarction (MI) or death. *Non invasive tests include:* Stress Echocardiograms – tests that compare blood flow with and without exercise and visualize the heart. Single-photon emission computed tomography (SPECT), also known as nuclear stress testing or myocardial perfusion imaging. *Invasive tests include:* The “gold” standard is the conventional coronary angiography which involves placement of a catheter and injection of contrast material into a large artery or vein, followed by 2-dimensional visualization with x-rays. Coronary computed tomographic angiography (CCTA) is a minimally invasive radiological technique used to provide images of the heart and surrounding vessels.

CCTA has been suggested as an alternative or useful complementary approach to other non-invasive methods of diagnosing coronary artery disease (CAD). Due to its ability to visualize coronary anatomy, CCTA has been suggested as a strategy to rule out significant CAD among patients at low or intermediate risk of significant disease, thereby giving greater reassurance than other non-invasive methods and potentially reducing the number of patients ultimately sent for invasive coronary angiography (ICA). Potential drawbacks include radiation exposure; duplicative or additional testing; incidental findings; and uncertainty about whether the test results in better health outcomes.

In September 2008, the HTA posted a draft and then followed with a final report from a contracted research organization that reviewed publicly submitted information; searched, summarized, and evaluated trials, articles, and other evidence about the topic. The comprehensive, public and peer reviewed, Computed Tomographic Angiography report is 125 pages, identified 8 relevant studies for the Emergency room setting and 34 relevant studies for outpatient, Medicare coverage and 4 expert treatment guidelines. These studies represent the best available information; including a randomized controlled trial for the emergency room setting from which evidence based conclusions were drawn.

An independent group of eleven clinicians who practice medicine locally meet in public to decide whether state agencies should pay for the health technology based on whether the evidence report and other presented information shows it is safe, effective and has value. The committee met on November 14th, reviewed the report, including peer and public feedback, and heard public and agency comments. Meeting minutes detailing the discussion are available through the HTA program or online at <http://www.hta.hca.wa.gov> in the committee section.

Summary of Committee Findings

The committee found that it had the most complete information: a comprehensive and current evidence report, public comments, and agency utilization information. The committee concluded that the current evidence on Computed Tomographic Angiography demonstrates that there is sufficient evidence a decision about use in an emergency

setting to cover investigation of acute chest pain in an emergency room department or hospital setting for those who are at low-to-intermediate risk of coronary artery disease. The committee concluded that there is not sufficient, reliable evidence developed to make a determination for other coronary CTA uses, including the outpatient setting. For low-to-intermediate risk patients in the Emergency department setting the diagnostic accuracy of the 64-slice as a triage tool was supported by one RCT and several case series. For low-to-intermediate risk outpatients, no RCT or long-term cohort evidence was available. Modeling suggests a lower rate of false negatives than SECHO and SPECT, and a lower rate of false positives than SPECT, but these differences change with underlying prevalence of CAD and involves other trade-offs.

Based on these evidentiary findings, the committee voted: 2 for non-coverage and 7 for coverage with conditions.

- ***Is it effective?***

The committee identified multiple key factors and health outcomes that were important for consideration in their overall decision on whether the technology was effective. Summary of committee consideration, discussion, and comments are listed below.

- ✓ *Diagnostic Accuracy – Sensitivity:* the committee agreed as a whole that CCTA has a high level of sensitivity. The technology report sensitivity rate was 98%; which compared favorably to stress echo at 76-94% and SPECT at 88-98%. The indeterminate rates were also lower, with CCTA at 3% versus Stress ECHO at 13% and SPECT at 9%.
- ✓ *Diagnostic Accuracy – Specificity:* the committee agreed equivalent specificity. Some uncertainty about lower prevalence population was shared amongst the committee members. The technology report specificity rate was comparable at 82-88%; compared to stress echo at 88% and SPECT at 77%.
- ✓ *Reduction in invasive CA:* the committee agreed that modeling suggests reduced ICA, but trial evidence data was inconclusive with Rubenstein trial showing reduction and Goldstein showing slight increase, especially when compared to alternative diagnostic tools.
- ✓ *Replace other tests:* most modeled analysis and clinical trials used CCTA in conjunction with other tests. Committee agreed that CCTA wouldn't replace other non-invasive technologies.
- ✓ *Incidental findings:* committee discussed as an issue both we respect to efficacy and safety and concluded that evidence demonstrates incidental findings are not infrequent events. Incidental findings can provide valuable information for diagnosis of previously undetected other diseases but also often leads to uncertainty or further tests to rule out questionable findings. The committee agreed that there is currently no evidence regarding improved patient health outcomes balancing cost and potential harms from further testing and anxiety.
- ✓ *Effect in real world:* Committee discussed several technology assessment key unknowns: whether more disease found will help or harm patients, especially at lower disease levels (clinical relevance is questionable); whether broad dissemination will result in lower test thresholds that may not result in better overall health outcomes but more radiation; and the extent to which CCTA can replace and not add to tests. Additionally, certification of machines and readers

was also discussed; hospitals require JAHCO accreditation and thus have some standards.

- ***Is it safe?***

The committee identified multiple key factors and health outcomes that were important for consideration in their overall decision on whether the technology was safe. Summary of committee consideration, discussion, and comments are listed below.

- ✓ *Radiation Exposure* is an important safety outcome to the committee. The committee discussed the technology assessment report findings of an overall cancer risk of .22% for women and .08% for men. Radiation dosage can be reduced through technique and machine type, but it is unknown whether these lowest dosage techniques/machines are used in WA settings. Overall exposure reported at between 2.0-8.0mSV for lower range is equivalent to SPECT; and 12.0 to 14.0 range for higher dose which is equivalent to A-bomb survivor at 2.3 kilometer distance. The committee concluded that there are small but definite risks, within appropriate norms. The radiation risks are high enough to obviate benefit when applied to very low risk patients.
- ✓ *Incidental findings* are also an important safety outcome that the committee discussed as an issue both we respect to efficacy and safety and concluded that evidence demonstrates incidental findings are not infrequent events. Incidental findings can provide valuable information for diagnosis of previously undetected other diseases but also often leads to uncertainty or further tests to rule out questionable findings. The committee agreed that there is currently no evidence regarding improved patient health outcomes balancing cost and potential harms from further testing and anxiety.

- ***Does it provide value (improve health outcome)?***

The committee discussed cost and cost-effectiveness as a whole. This topic generated the least discussion. There are several cost studies for ED and outpatient showing cost savings. The technology assessment report also modeled costs for ED and outpatient showing cost savings using Medicare reimbursement rates. No analysis included costs related to incidental findings or harms. Current state agency reimbursement rates do not correlate with modeled costs (Agency reimbursement for CCTA is higher and for comparators is lower).

- ✓ Committee members were split, with four considering the cost effectiveness currently unproven and five concluding that CCTA is either equivalent or more cost effective in some situations.

Consistency with Medicare Decision and Expert Treatment Guidelines

Committee reviewed and discussed the Medicare coverage decision and expert guidelines as identified and reported in the technology assessment report.

- There is no national coverage decision (NCD), however a coverage analysis and memo was issued in 2008 and summarized: there is uncertainty regarding any potential health benefits or patient management alterations from including coronary CTA in the diagnostic workup of patients who may have CAD. No adequately powered study has established that improved health outcomes can be casually attributed to coronary CTA for any well-defined clinical indication, and the body of evidence is of overall limited quality and limited applicability to Medicare patients

with typical co-morbidities in community practice. The primary safety concerns with cardiac CTA are the exposure to radiation and the use of contrast and blocker medications.

- Four expert guidelines were identified that address the use of CCTA for detection of CAD, but not the setting (ED versus outpatient).
 - American Heart Association (2006): evidence supports the use of CCTA for patients with low-to-intermediate stenosis and may obviate the need for ICA.
 - Multi-Society Statement of Appropriateness Criteria for Cardiac Computed Tomography (2006): Appropriateness reviews deemed the use of CCTA for detection of CAD to be appropriate for the following patient populations: chest pain syndrome with intermediate pre-test probability of CAD and uninterpretable EKG or inability to exercise; chest pain and uninterpretable or equivocal stress test results; acute chest pain with intermediate pre-test probability of CAD and no EKG changes and serial enzymes negative; and symptomatic patients requiring evaluation of suspected coronary anomalies.
 - American College of Radiology (2006): CCTA is appropriate for assessment of CAD, although its usefulness for patients with low pre-test probability is unknown. Appropriateness rating of 7 out of 9 for the evaluation of chronic chest pain.
 - SCCT/NASCI Consensus Update (2007): CCTA to be appropriate in the following circumstances: (1) to rule out significant coronary stenosis; (2) to evaluate patients with equivocal or discordant results on a stress perfusion or wall motion study; (3) to rule out stenosis in patients with a low pre-test likelihood of CAD and (4) to potentially replace diagnostic catheterization in patients undergoing non-coronary cardiac surgery.

The committee concluded that their decision is consistent with applicable policy and guidelines. There is no national Medicare coverage decision. The decision is consistent with treatment guidelines in that low to intermediate triage will be covered, with the coverage decision being more specific in identifying the place of service. The committee decision is based on all evidence, including public and agency comments and the comprehensive technology assessment report.

Committee Authority

Washington State believes it is important to use a scientific based, clinician centered approach for difficult and important health care benefit decisions. The HTA gathers and assesses the quality of the latest medical evidence using a scientific research company, takes public input at all stages, and asks a committee of eleven independent health care professionals to review all the information and render a decision at an open meeting. The Washington State [Health Technology Clinical Committee \(HTCC\)](#), an independent committee of 11 health practitioners, determines how selected health technologies are covered by several state agencies. See RCW 70.14.080-140. These technologies may include medical or surgical devices and procedures, medical equipment, and diagnostic tests. HTCC bases their decisions on the evidence of the technology's safety, efficacy, and cost effectiveness. Participating state agencies are required to comply with the decisions of the HTCC. HTCC decisions may be re-reviewed at the determination of the HCA Administrator.



Missed Lumbar Disc Herniations Diagnosed With Kinetic Magnetic Resonance Imaging

Jun Zou, MD,* Huilin Yang, MD, PhD,* Masashi Miyazaki, MD,† Feng Wei, MD, PhD,†
Soon W. Hong, MD,† Seung H. Yoon, MD,† Yuichiro Morishita, MD,†
and Jeffrey C. Wang, MD†

Study Design. A novel dynamic magnetic resonance imaging (MRI) system, kinetic MRI (kMRI), was used to study lumbar disc herniations.

Objective. The objective of this study was to determine if adding flexion and extension MRI studies to the traditional neutral views would be beneficial in the diagnosis of lumbar disc herniations.

Summary of Background Data. Prior studies demonstrate that only 70% of patients with lumbar disc herniations based on physical examinations are confirmed by MRI studies. Recently, kMRI delivers the ability to scan patients in neutral, flexion, and extension positions, which may allow for improved diagnosis of this problem.

Methods. Five hundred fifty-three patients underwent kMRI with assessment of the degree of disc bulge in neutral and flexion and extension. The images were analyzed using computer measurement technology to objectively quantify the amount of disc herniation.

Results. For patients with normal or <3 mm of disc bulge in neutral, 19.46% demonstrated an increase in herniation to >3 mm bulge in extension, and 15.29% demonstrated an increase to >3 mm bulge in flexion. For patients in the neutral view that had a baseline disc bulge of 3 to 5 mm, 13.28% had increased herniations to >5 mm in extension and 8.47% had increased herniations to >5 mm in flexion. For patients with a baseline disc bulge of 5 to 7 mm in neutral, 10.58% increased in extension and 5.78% increased in flexion. In addition, for patients with a baseline disc bulge of 7 to 9 mm in neutral, 9.09% increased in extension and 4.55% increased in flexion.

Conclusion. A significant increase in the degree of lumbar disc herniation was found by examining flexion and extension views when compared with neutral views alone. kMRI views provide valuable added information, especially in situations where symptomatic radiculopathy is present without any abnormalities demonstrated on conventional MRI.

Key words: kinetic MRI, lumbar disc herniation, missed diagnosis. *Spine* 2008;33:E140–E144

on low back pain. One common reason for lower back pain is herniation of the intervertebral disc into the spinal canal. In the United States in 2003, the National Hospital Discharge Survey reported that 3,57,000 procedures were performed for disorders of the intervertebral disc,² 8.5% higher than in 2000.³

Magnetic resonance imaging (MRI) is a good tool most frequently used for lumbar disc herniation because it can show abnormal areas of soft tissue around the spine. However, traditional MRI has significant limitations, although it reveals musculoskeletal disease. The patients are placed in a horizontal, nonweight-bearing position where conventional scans may not reveal the causative pathology. However, only 70% of patients who were diagnosed with a lumbar disc herniation based on clinical examination had a lumbar disc herniation confirmed by MRI.⁴

Recently, kinetic MRI (kMRI) permits us to image the patient in a weight-bearing position (either standing up or sitting), and in the flexed and extended positions, which can, of course, reveal abnormalities that were missed by a conventional MRI study. It may supply a more thorough investigation of each patient and allow us to better understand the true nature of the pathology. Imaging the spine in the weight-bearing position with extension and flexion or placing the spine in the position of pain may increase the diagnostic accuracy for the surgeons. The purpose of this study was to study the use of kMRI for evaluation of missed herniated discs when compared with conventional MRI studies and to determine the changes in the disc herniations according to the flexed and extended positions.

Materials and Methods

Study Population

From July 2005 through July 2006, 553 patients with symptomatic back pain with/without radiculopathy were referred to kMRI for lumbar MRI examination. There were 234 males and 319 females. The mean age was 46.2 years (range, 18–76 years). This represented 2765 lumbar discs in total.

Imaging Instrumentation

MRI of the lumbar spine was performed by using a 0.6 Tesla MRI scanner (Fonar Corp. UPRIGHTTM, Multi-Position, NY, NY). The MR unit uses a vertical orientation of the 2 opposing magnet doughnuts, allowing scanning of the patient in an upright axially loaded position. An 18-inch gap between the magnets is present. Images were obtained using a quad channel planar coil. T1 weighted sagittal spin echo images (repetition time 671 milliseconds, echo time 17 mil-

Lower back pain is the second most common reason for physician visits in the United States, second only to colds and flu.¹ Americans spend at least \$50 billion each year

From the *Department of Orthopedic Surgery, The First Affiliated Hospital of Soochow University, Suzhou, China; and †Department of Orthopedic Surgery, UCLA, Los Angeles, CA.

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The manuscript submitted does not contain information about medical device(s)/drug(s).

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Address correspondence and reprint requests to Jeffrey C. Wang, Department of Orthopaedic Surgery, University of California, Los Angeles, CA 90095; E-mail: jwang@mednet

liseconds, thickness 4.0 mm, field of view 30 cm, matrix 256×224 , NEX 2) and T2 weighted fast spin echo images (repetition time 3000 milliseconds, echo time 140 milliseconds, thickness 4.0 mm, field of view 30 cm, matrix 256×224 , NEX 2, flip angle).

Procedure

Patients were placed in the upright axially loaded neutral position (T1 and T2 weighted images) and upright axially loaded flexion and extension positions (T2 weighted Fast Spin Echo images only). Five-level units (L1/L2, L2/L3, L3/L4, L4/L5, L5/S1) were chosen from these patients and assessed on the T2-weighted midsagittal images.

For each film, points were marked for digitization by a fellowship-trained spine surgeon. From L1–S1, the vertebral body was marked as 4 points (corner of anterior-inferior, anterior-superior, posterior-superior, posterior-inferior) and disc height was marked as 2 points (middle of endplate), pedicle diameter and spinal cord diameter was marked as 2 points.

The disc bulge on MRI was recorded on computer-based measurement and all calculations were done using MRI Analyzer Version 3 (TruMetric Corp., Bellflower, CA) anatomic software to objectively quantify the amount of disc bulge in millimeters.

Evaluation

To ascertain the missed diagnosis of lumbar disc herniations, the extent of lumbar disc bulges in neutral, flexed, and extended views were graded as follows: grade 1, (no disc bulge or disc bulge, <3 mm); grade 2 (disc bulge, 3–5 mm); grade 3 (disc bulge, 5–7 mm); grade 4 (disc bulge, 7–9 mm); and grade 5 (disc bulge, >9 mm). All lumbar segments were evaluated and recorded. A functional disc bulge was considered present if the disc was bulged or was more bulged after lumbar flexion or extension. “More bulged” was defined by means of measurement of an increase in the bulged disc size after lumbar flexion or extension, which was considered a positive finding. This evaluation was performed by 2 spine surgeons independently without knowing the patient’s history and clinical findings.

Statistical Analysis

The statistical significance was calculated using the χ^2 test and the paired *t* test. Data were analyzed with a software program (SPSS, version 13, Chicago, IL). All significance levels were set at $P < 0.05$.

Results

Dynamic Change in Lumbar Disc Herniations During Lumbar Extension and Flexion

On extension images, the pair *T*-test showed significant increases in disc herniation from the neutral position to the extension position at each level ($P < 0.005$). The results were as followed: L1/L2 (2.12 ± 1.06 vs. 2.39 ± 1.83 mm), L2/L3 (2.44 ± 1.24 vs. 2.69 ± 1.77 mm), L3/L4 (2.78 ± 1.28 vs. 3.08 ± 2.25 mm), L4/L5 (3.48 ± 1.59 vs. 3.82 ± 2.47 mm), and L5/S1 (3.45 ± 1.78 vs. 3.77 ± 2.58 mm). On extension images, the pair *T*-test showed significant differences only at L3/L4 and L4/L5 from the neutral position to the flexion position, L3/L4 (2.78 ± 1.28 vs. 2.68 ± 1.33 mm), L4/L5 (3.48 ± 1.59 vs. 3.34 ± 1.57 mm) ($P < 0.05$). There were no signifi-

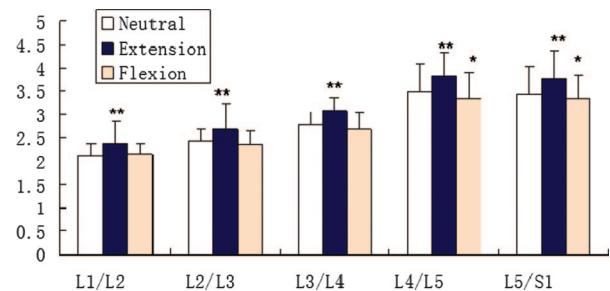


Figure 1. Bar graph shows dynamic changes in lumbar disc herniation during lumbar extension and flexion. The values of lumbar disc herniation (mean \pm SD) in the extension and flexion views were compared with the neutral view ($*P < 0.05$, $**P < 0.01$).

cant changes at L1/L2 (2.12 ± 1.06 vs. 2.15 ± 1.24 mm), L2/L3 (2.44 ± 1.24 vs. 2.36 ± 1.30 mm), and L5/S1 (3.45 ± 1.78 vs. 3.34 ± 1.70 mm) ($P > 0.05$) (Figure 1). Distribution of lumbar disc herniation among neutral, extension, and flexion images is showed in the Table 1. On neutral views, the disc bulge was classified as grade 1 in 1557 (56.31%) of the 2765 discs, grade 2 in 956 (35.58%), grade 3 in 208 (7.52%), and grade 4 in 44 (1.59%). 1254 in the grade 1, 1132 in the grade 2, 313 in the grade 3, 62 in the grade 4, 4 in the grade 5 were noted at extension images. 1319 in the grade 1, 1113 in the grade 2, 277 in the grade 3, 54 in the grade 4, 2 in the grade 5 were noted on flexion images (Table 1). Increased disc bulge at extension and flexion MRI was seen in 456 (16.49%) and 333 (12.04%) discs, respectively.

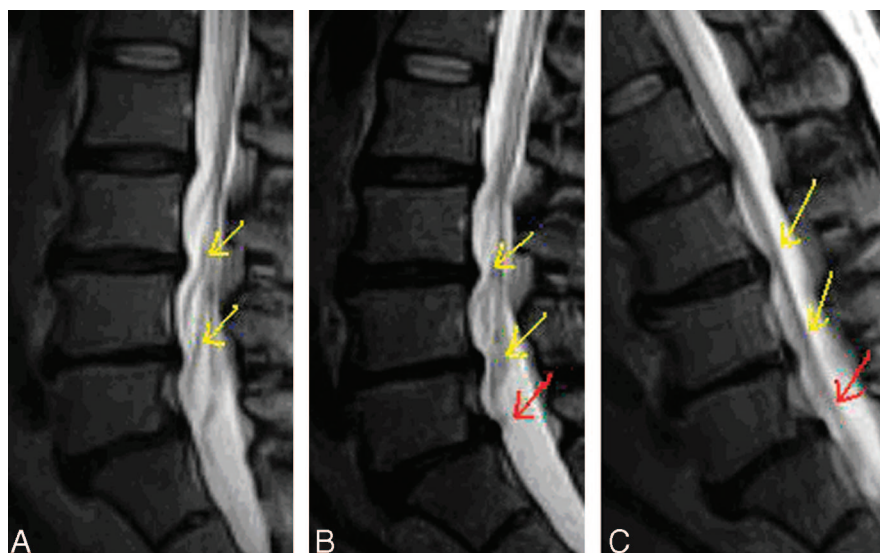
Incidence of Missed Diagnosis of Lumbar Disc Herniation Showed by Extension and Flexion Images

On extension MRI in the grade 1 group, grade 1 of lumbar disc herniation was maintained in 1254 (80.54%) of the 1557 discs and progressed to a more advanced grade in 303 discs. The incidence of a missed diagnosis of a disc herniation in this group is 19.46%. In the grade 2 group, disc bulges in 829 (86.72%) of the 956 discs maintained grade 2, but 127 (13.28%) discs progressed to grade 3. In the grade 3 group on extension MRI, the disc bulge was more severe than in neutral position in 22 (10.58%) of the 208 discs and was maintained at grade 3 in 186 (89.42%). In the grade 4 group, disc bulge in 40 discs (90.91%) of the 44 discs maintained grade 4 and progressed to grade 5 in 4 (9.09%). The χ^2 test showed significant difference between these 4 groups for increasing disc herniation during extension ($P < 0.05$). On flexion MRI, lumbar disc herniations maintained grade 1 in

Table 1. Distribution of Lumbar Disc Herniation Among Neutral, Extension, and Flexion Images

	Grade 1 (0–3 mm)	Grade 2 (3–5 mm)	Grade 3 (5–7 mm)	Grade 4 (7–9 mm)	Grade 5 (>9 mm)
Neutral	1557	956	208	44	0
Extension	1254	1132	313	62	4
Flexion	1319	1113	277	54	2

Figure 2. Lumbar disc herniation in a 58-year-old man. In the neutral position (A), T2-weighted sagittal MR image shows L2–L3, L3–L4, and L4–L5 levels disc herniation. In extension (B) and flexion (C), a new disc herniation (L5–S1 level) is noted. And more severe disc bulges are also seen in the both L3–L4 and L4–L5 levels.



1319 (84.71%) of 1557 discs and progressed to grade 2 in 238 (15.29%). In the grade 2 group, disc bulge in 875 (91.53%) of the 956 discs maintained grade 2 and progressed to grade 3 in 81 (8.47%). In the grade 3 group on extension MRI, disc bulge was more severe than that in neutral position in 12 (5.78%) of the 208 discs and was maintained at grade 3 in 196 (94.22%). In the grade 4 group, disc bulge in 42 (95.45%) of the 44 discs maintained grade 4 and progressed to grade 5 in 2 (4.55%) (Figure 2). The Fisher's exact test showed significant difference these 4 groups for increasing disc herniation during flexion ($P < 0.05$). With regard to the grade of disc herniation, the χ^2 test was used to examine the difference between extension and flexion imaging. There are significant differences in all grades ($\chi^2 = 16.19, 14.11, 5.06$, respectively, $P < 0.05$) except grade 4 ($\chi^2 = 0.5, P > 0.05$) (Table 2).

Discussion

Since chronic low back pain is not a single factorial disease, it has various etiologies. However, low back pain has been believed in some cases to be related to the intervertebral disc, the surrounding soft tissue, or the facet joints. MRI has become the examination of choice for diagnosing lumbar disc herniation.⁵ The pros of it is that it has no known side effects, no radiation exposure, and noninvasive. In fact, weight bearing, flexion, extension,

or lateral bending may change anatomic relationships. Compressive load can increase the load in the lumbar spine by 80% compared with that in the supine position.⁶ In addition, the intradiscal pressure also changes with the position of spine where it increases in standing, sitting, and in a forward flexed position.⁷ Prolonged standing can diminish the size of the neural foramina and central spinal canal because the discs lose water content and height whenever the load on the spine is increased. Axial loading of the spine decreases the disc height measured on MR images, and axial compression of the spine also causes bulging of the intervertebral disc and narrowing of the diameters of the neural foramen and central canal. Scanning patients in a recumbent position may potentially miss an occult disc herniation, which may be revealed in a weight-bearing or more positional mode such as flexion or extension. Radiologists failed to report certain pathologic findings, which had to be handled during the surgery. Cases where there is such limited association between diagnostic imaging and clinical symptoms perplexed surgeons a long time.

Flexion and extension radiographs and computed tomography myelography were the standard methods of obtaining positional images of the spine. However, because MRI yields an image that is superior to radiographs and less invasive than myelography, physicians have been experimenting with ways of using MRI to obtain positional images of spine. To help in a better understanding of the pathophysiology of the spine, there seems to be a need for further developments in functional clinical imaging.

Cartolari⁸ set up an axial-loaded computed tomography and MR technology by pressing on the recumbent patients' shoulders with 70% body weight. Smith⁹ figured out a study of 25 patients with low back pain and sciatica for lumbar spine upright MRI. Upright MRI demonstrated abnormalities in 13 patients (52%) that were not evident in the recumbent posture. There were 3 cases with lateral disc herniations, 6 cases with hypermo-

Table 2. Incidence of Missed Diagnosis of Lumbar Disc Herniation Shown by Extension and Flexion Images

Grade of Disc Bulge (in the Neutral Position)	Extension	Flexion	χ^2
Grade 1 (<3 mm)	19.46% (303/1557)	15.29% (238/1557)	16.19*
Grade 2 (3–5 mm)	13.28% (127/956)	8.47% (81/956)	14.11*
Grade 3 (5–7 mm)	10.58% (22/208)	5.78% (12/208)	5.06†
Grade 4 (7–9 mm)	9.09% (4/44)	4.55% (2/44)	0.5

* $P < 0.01$.

† $P < 0.05$.

bile disc at 1 or more levels, 2 cases with previously unsuspected grade 1 spondylolisthesis, and 2 cases with significant stenosis. Powers *et al*¹⁰ qualified segmental mobility of the lumbar spine during a posterior to anterior spinal mobilization procedure. Eleven asymptomatic subjects were positioned prone within a vertically open double donut design MRI system. An anteriorly directed force was applied manually at each lumbar spinous process. The result showed that the posterior to anterior force applied at the upper lumbar vertebrae (L1–L2) consequently decreased the lumbar lordosis. Force applied on the other vertebrae (L3–L5) resulted in an increased lumbar lordosis. That indicted how passive movement technique influenced segmental motion of healthy spines, which is important of understanding how altered mobility is related to symptoms. Karadimas *et al*¹¹ investigate how the degree of lumbar segmental degeneration affects sagittal changes in the lumbar spine as it shifts from the supine to the sitting (load-bearing) posture by conventional supine MRI and positional MRI. With positional MRI, they were able to demonstrate changes in healthy and degenerative discs in the weight-bearing position. As the lumbar spine was loaded from the supine to the sitting position, the endplate angles were decreased significantly as the degeneration was increased. There were also significant changes in the anterior and middle disc heights between the supine and the sitting postures irrespective of the degree of degeneration. The overall lumbar lordosis did not significantly change between the 2 postures.

Today, kMRI, a system using vertical magnets with 0.6 T midfield strength, delivers the ability to scan patients in a weight-bearing position. This allows us to image patients in the exact position that elicits symptoms and provide for a detailed evaluation of musculoskeletal pathology. The potential relative beneficial aspects of kMRI spinal imaging on this system, over that of conventional MRI, is the potential unmasking of positionally related pathologies and the potential ability to scan the patient in the position of clinically relevant signs and symptoms. kMRI may prove to be efficacious to incorporate as a part of the clinical diagnosis—treatment paradigm in patients with spinal, radicular, and referred pain syndromes originating from spinal pathology. Furthermore, kMRI may better relate the patient's clinical symptoms objective images demonstrating pathology, which may be more specific and sensitive than conventional MRI studies.

In the present study, we found that kMRI could improve the detection of lumbar disc herniations. A significant increase in the degree of lumbar disc herniation was found by examining flexion and extension views when compared with neutral views alone. Using extension MRI alone compared with conventional MRI, the incidence of missed disc herniations is up to 19.46% (303/1557). Using only flexion MRI compared with conventional MRI, the incidence of missed disc herniations is up to 15.29% (238/1557). This also suggests that extension

MRI views yield a higher detection rate of missed lumbar disc herniations than flexion views (456 discs, 16.49% *vs.* 333 discs, 12.04%). Flexion and extension MRI views provide valuable, added information when assessing patients for lumbar disc herniations, and may be especially useful in situations where symptomatic radiculopathy is present with unimpressive conventional MRI studies.

This imaging technology may prove to be useful to reveal hidden pathologies not only in occult disc herniations, but also in the other degenerative spinal disease. kMRI may be able to detect occult stenosis or occult instability in the spine by placing the spine in a weight-bearing position. In addition, it may reveal occult nerve root impingement by placing the patient's spine in the position that causes pain or in a position that should narrow the spinal canal and neural foramen (such as spinal extension). In addition, large or claustrophobic patients or patients who need to be scanned in an upright position because of congestive heart failure, severe chronic obstructive pulmonary disease, or severe spinal kyphosis, can be handled by this novel MRI.

■ Key Points

- Prior studies demonstrate that only 70% of patients who were clinically diagnosed with lumbar disc herniations based on physical examinations had lumbar disc herniations confirmed by MRI studies.
- A novel dynamic magnetic resonance imaging system, Kinetic MRI (kMRI), delivers the ability to scan patients in neutral, flexion, and extension positions, which may allow for improved diagnosis of this problem.
- Our study demonstrated that the disc herniations did change with the different positions of the spine.
- kMRI views could improve detection of missed lumbar disc herniations, and provide valuable added information, especially in situations where symptomatic radiculopathy is present without any abnormalities demonstrated on conventional MRI.

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Kinematic Analysis of the Relationship Between the Grade of Disc Degeneration and Motion Unit of the Cervical Spine

Masashi Miyazaki, MD,* Soon Woo Hong, MD, PhD,* Seung Hwan Yoon, MD, PhD,* Jun Zou, MD,* Benjamin Tow, MD,* Ahmet Alanay, MD,† Jean-Jacques Abitbol, MD,‡ and Jeffrey C. Wang, MD*

Study Design. Kinetic MRIs of cervical spines were obtained and analyzed according to the amount of motion and the degenerative grade of the intervertebral disc.

Objective. To define the relationship between the grade of disc degeneration and the motion unit of the cervical spine and elucidate changes in the role of each cervical spine unit during flexion-extension motion caused by degeneration.

Summary of Background Data. Degenerative changes in the cervical disc occur with age. The correlation between the degree of cervical disc degeneration and extent of cervical spine mobility has not yet been determined. The effect of degeneration on the overall motion of the functional spinal unit also remains undefined.

Methods. We studied 164 patients with symptomatic neck pain. The cervical intervertebral discs were graded by spine surgeons according to the degenerative grading system (Grades I to V). All radiologic data from kinetic MRIs were recorded on a computer for subsequent measurements. All measurements and calculations for translational motion and angular variation of each segment were automatically performed by a computer analyzer.

Results. The translational motion in discs with Grade II degeneration (mild degeneration) increased to Grade III degeneration (higher degeneration). However, the translational motion and angular variation significantly decreased for the Grade V (severe degeneration). For patients with relatively low grades of degeneration, Grades I and II discs, the C4–C5 and C5–C6 segmental units contributed the majority of total angular mobility of the spine. However, for the severely degenerated segments, Grade V discs, the contributions of the C4–C5 and C5–C6 U significantly decreased.

Conclusion. The changes that occur with disc degeneration progress from the normal state to an unstable phase with higher mobility and subsequently to an ankylosed

stage. This study evaluated the contribution of different levels to the changes in overall motion that occur with degeneration.

Key words: kinematic analysis, disc degeneration, cervical spine, intervertebral disc, kinetic magnetic resonance imaging. **Spine 2008;33:187–193**

Cervical disc degeneration is common after middle age and is part of the normal aging process.^{1–4} The degenerative changes generally occur gradually and frequently without significant symptoms; however, some individuals become symptomatic. Progressive degeneration affects the motion units and overall kinematics of the cervical spine.⁵ One of the primary functions of the cervical spine is to control head and neck motion. Cervical instability has long been considered as a contributor to neck and back pain.^{6–9} Many motion studies have been performed to define normal flexibility and to determine the relationship between abnormal motion and neck and related pain conditions.^{10–13} The correlation between the degree of cervical disc degeneration and the extent of cervical spine mobility has not yet been determined. The effect of degeneration on the overall motion of the functional spinal unit also remains undefined.

Many investigators have measured this motion using simple flexion and extension radiographs.^{10,12,13} The accuracy of an analysis performed using simple radiographs depends on methodology. Generally, it increases with the complexity of the methodology; however, its practicality in routine clinical applications consequently decreases. The radiostereometric method provides accurate tracking of motion¹⁴; however, it necessarily involves the implantation of metal markers. Hence, the use of this invasive method is not practical in many clinical scenarios.

Kinetic MRI studies can noninvasively demonstrate the mobility of each motion segment and define the region of spine motion.^{15–17} Degeneration is caused by the loss of both proteoglycan and water in the disc and is detected by the loss of signal intensity on T2-weighted images.¹⁸ It induces structural changes in the disc and a decrease in disc height, which can be visualized on MR images.^{19,20} Thus, kinetic MRI can relate the grade of degeneration to the extent of cervical spine mobility. In addition, a recently developed computer-assisted calculation method facilitates the measurement of segmental

From the *Department of Orthopaedic Surgery, University of California at Los Angeles, Los Angeles, CA; †Department of Orthopaedics and Traumatology, Faculty of Medicine, Hacettepe University, Sıhhiye, Ankara 06100, Turkey; and ‡Department of Orthopaedics, University of California at San Diego, San Diego, CA.

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Address correspondence and reprint requests to Jeffrey C. Wang, MD, Chief, Orthopaedic Spine Service, Associate Professor of Orthopaedics and Neurosurgery and Biomedical Engineering, UCLA Comprehensive Spine Center, 1250 16th Street, Suite 745, Santa Monica, CA 90404, USA; E-mail: JWang@mednet.ucla.edu

Table 1. Grading System for Cervical Intervertebral Disc Degeneration

Grade	Nucleus Signal Intensity	Nucleus Structure	Distinction of Nucleus and Annulus	Disc Height
I	Hyperintense	Homogenous, white	Clear	Normal
II	Hyperintense	Inhomogenous with horizontal band, white	Clear	Normal
III	Intermediate	Inhomogenous, gray to black	Unclear	Normal to decreased
IV	Hypointense	Inhomogenous, gray to black	Lost	Normal to decreased
V	Hypointense	Inhomogenous, gray to black	Lost	Collapsed

angular variation and translational motion and the comparison of different positional (flexion/neutral/extension) MRIs.^{10,11}

In this study, the relationship was studied between the grade of disc degeneration and the motion of the cervical spine units in patients with cervical pain using kinetic MRI. In addition, this study aimed to elucidate changes in the role of each cervical spine unit during flexion-extension motion in patients with disc degeneration using kinetic MRI.

Materials and Methods

A Grading System for Cervical Intervertebral Disc Degeneration and Its Reliability

A comprehensive grading system for cervical disc degeneration was developed based on the reported literature²¹⁻²⁵ (Table 1, Figure 1). The cervical intervertebral discs were graded by spinal surgeon observers according to this grading system by using T2-weighted sagittal images.

Intra/Interobserver Reliability. T2-weighted sagittal images were used by 3 spine surgeon observers (A-C) to Grade 300 cases of cervical intervertebral disc degeneration in a blinded

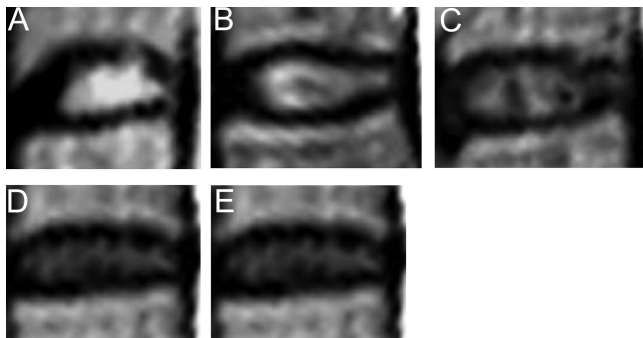


Figure 1. Grading system for cervical intervertebral disc degeneration. **A**, Grade I: Nucleus signal intensity is hyperintense and nucleus structure is homogeneous, white. Distinction of nucleus and annulus is clear. Disc height is normal. **B**, Grade II: Nucleus signal intensity is hyperintense and nucleus structure is inhomogeneous with horizontal band, white. Distinction of nucleus and annulus is clear. Disc height is normal. **C**, Grade III: Nucleus signal intensity is intermediate and nucleus structure is inhomogeneous, gray to black. Distinction of nucleus and annulus is unclear. Disc height is normal to decrease. **D**, Grade IV: Nucleus signal intensity is hypointense and nucleus structure is inhomogeneous, gray to black. Distinction of nucleus and annulus is lost. Disc height is normal to decrease. **E**, Grade V: Nucleus signal intensity is hypointense and nucleus structure is inhomogeneous, gray to black. Distinction of nucleus and annulus is lost. Disc height is collapsed. Grading was performed on T2-weighted midsagittal images.

fashion. All the MRIs were separately analyzed with a minimum interval of 1 week. A set of typical sample MRIs (Table 1, Figure 1) was available to the observers during the image review.

Participants

Kinetic MRI scans of the cervical spine were consecutively obtained over a 6-month period from February 2006 to July 2006. In this study, 168 patients with symptomatic neck pain with/without radiculopathy or myelopathy were enrolled; of these, 164 consecutive patients (69 men and 95 women) were selected based on the image findings. The mean age of the selected patients was 44 years (range, 19-93 years). All the selected

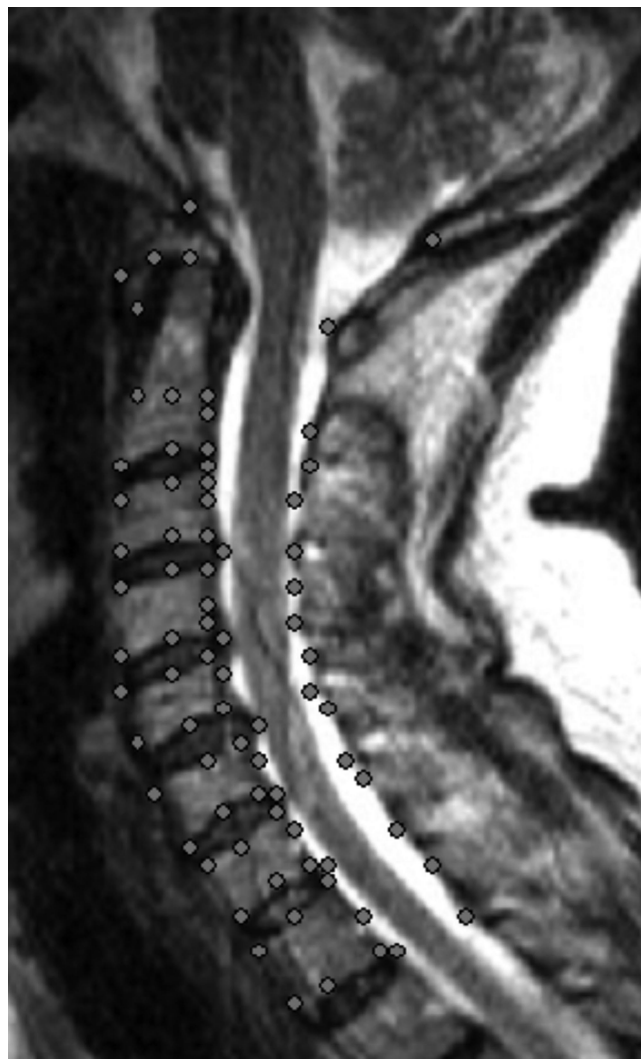


Figure 2. In each film, 77 points were marked for digitization.

patients were referred for cervical kinetic MRI scans because they exhibited cervicobrachial pain symptoms. None of the patients had previously undergone cervical spinal surgery. This study selected 6 level units (C2–C3, C3–C4, C4–C5, C5–C6, C6–C7, and C7–T1) and assessed a total of 492 T2-weighted midsagittal images.

MRI Positioning

With each patient in a sitting posture, neck flexion and extension were actively performed. The same amount of flexion extension is performed in all the 3 positions (40° flexion, 0° neutral, and –20° extension positions).

Image Analysis

MR imaging of the cervical spine was performed using a 0.6-Tesla MRI scanner (Fonar Corp. Upright Multi-Position, New York, NY) and a flexible surface coil. The MR unit uses a vertical orientation of 2 opposing magnet doughnuts, permitting scanning of the patient in an upright axially loaded position. There was an 18-in gap between the magnets. The patients were examined using T1-weighted sagittal spin-echo images (repetition time, 671 ms; echo time, 17 ms; thickness, 3.0 mm; field of view, 24 cm; matrix, 256 × 200; number of excitations (NEX), 2) and T2-weighted sagittal fast spin-echo images (repetition time, 3432 ms; echo time, 160 ms; thickness, 3.0 mm; field of view, 24 cm; matrix, 256 × 224; NEX, 2).

All radiologic data obtained from the MRIs were recorded on a computer for subsequent measurements, and all calculations were automatically performed on true MRI by a MRI analyzer. For each image, 77 points were marked for digitization by the spine surgeons. Specific points were selected for the

Table 2. Cervical Disc Degeneration Grading

Level	Grade I	Grade II	Grade III	Grade IV	Grade V
C2–C3	12	19	75	58	0
C3–C4	12	18	66	60	8
C4–C5	9	12	73	53	17
C5–C6	8	16	57	40	43
C6–C7	17	35	57	29	26
C7–T1	33	60	55	10	6

occiput (Oc) and C1 and C2 vertebrae. Anterior and posterior baselines were marked at the Oc. Anterior tubercle and posterior margin of the atlas and the lowest end of the spinous process were marked at C1. At C2, 1 point was marked at the tip of the odontoid process and others, corresponding to C3 to T1. For each of the typical cervical vertebrae from C3 to T1, the vertebral body was denoted by 4 points (anterior-inferior, anterior-superior, posterior-superior, and posterior-inferior corners); disc height, by 2 points (middle of endplate); and the pedicle and spinal cord diameters, by 2 points each (Figure 2).

The basic measurements involved calculations of all the static intervertebral angular displacements and translations in different positions. Subsequently, total flexibility (motion segment integrity, translational motion, and angular variation) was calculated at each vertebral level from the difference in flexibilities in the flexion and extension positions. Translational motion was measured in 6 levels (C2–C3, C3–C4, C4–C5, C5–C6, C6–C7, and C7–T1 level) by determining the anteroposterior motion of 1 vertebra over another; a positive value indicated anterior translation (antelisthesis), whereas a negative value indicated posterior translation (retrolisthesis). Angular variation was measured in 5 levels (C2–C3, C3–C4, C4–C5, C5–C6, and C6–C7 level). For determining angular variation, lines were drawn through the inferior borders of 2 vertebral bodies adjacent to the corresponding vertebral levels. The lordotic angle was defined as negative, whereas the kyphotic angle, as positive (Figure 3). Both translational motion and angular variation, total movements (flexion to extension) were calculated at each level. Total number of assessed discs for translation motion was 984 discs, and total number of assessed discs for angular variation was 820 discs.

To elucidate changes in the role of each cervical spine unit during flexion-extension motion caused by degeneration, we estimated the contribution of each intervertebral level to total angular mobility.

Contribution of each level to total angular mobility (%) = (angulation of each unit in degrees)/(angulation of C1–C2 + C2–C3 + C3–C4 + C5–C6 + C6–C7 in degrees) × 100.

Statistical Analysis

Statistical analysis was performed using the computer program SPSS (version 13, SPSS Inc., Chicago, IL), and values were expressed as mean ± standard deviation (SD). Student *t* test was performed with a significance level of 0.05. Intra and in-

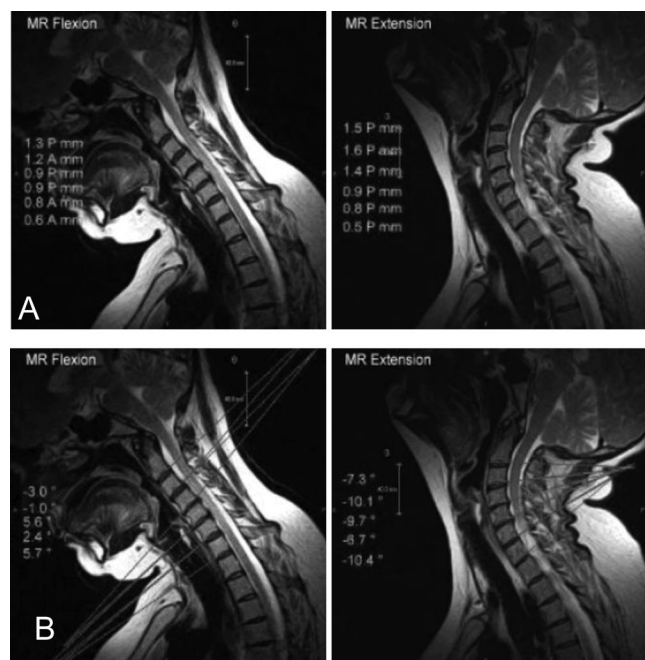


Figure 3. Motion segment integrity translational motion and angular variation. **A**, For the translation, motion is measured by determining the anteroposterior motion of one vertebra over another and a positive value meant anterior translation (antelisthesis), whereas a negative value meant posterior translation (retrolisthesis). **B**, For the angular variation, lines are drawn the inferior borders of 2 vertebral bodies adjacent to the level. The lordotic angle was defined as negative, whereas the kyphotic angle was defined as positive.

Table 3. Intra- and Interobserver Reliability

Intraobserver	Kappa	Interobserver	Kappa
A1–2	0.907	A1–B1	0.779
B1–2	0.950	A1–C1	0.752
C1–2	0.933	B1–C1	0.730

Table 4. Translational Motion for Each Cervical Unit (mm)

Level	Grade I	Grade II	Grade III	Grade IV	Grade V
C2–C3	1.02 ± 0.90	0.96 ± 0.79	1.12 ± 0.75	1.17 ± 0.92	NA
C3–C4	1.36 ± 0.78	1.16 ± 0.96	1.40 ± 0.83	1.36 ± 0.84	0.95 ± 0.66
C4–C5	1.19 ± 0.71	1.55 ± 0.73	1.22 ± 0.91	1.32 ± 0.89	0.88 ± 0.59*
C5–C6	0.71 ± 0.53	1.15 ± 0.80	1.16 ± 0.80	1.42 ± 1.38	0.90 ± 0.70*
C6–C7	0.82 ± 0.68	0.86 ± 0.56	1.08 ± 1.37	0.85 ± 0.69	1.01 ± 0.80
C7–T1	0.69 ± 0.46	0.64 ± 0.50	1.01 ± 0.64*	1.00 ± 0.70	0.63 ± 0.40

Values are expressed mean ± SD.

* $P < 0.05$ compared to immediate less degenerative grade at same level.

terobserver reliability of the MRI evaluations was estimated using kappa statistics²⁶ and interpreted according to the guidelines suggested by Landis and Koch.²⁷ The levels of agreement were rated as follows: kappa value of 0 to 0.2 indicated poor agreement; 0.21 to 0.4, fair agreement; 0.41 to 0.60, moderate agreement; 0.61 to 0.8, substantial agreement; and 0.81, upward excellent agreement. A value of 1 indicated absolute agreement, whereas 0, agreement no better than chance.

■ Results

Grades of Cervical Disc Degeneration in the Study Population

A total of 984 cervical discs were graded in a study population of 164 individuals. The amount of disc degeneration corresponding to each grade is summarized in Table 2. For Grade I (almost normal) discs, the amount of disc degeneration is relatively lower at the C4–C5 and C5–C6 levels than at the other levels. In contrast, it is higher at the C4–C5, C5–C6, and C6–C7 levels than at the C2–C3, C3–C4, and C7–T1 levels for Grade V (severe degeneration) discs.

Kappa Values for Intra- and Interobserver Agreement

The estimated kappa values for intra and interobserver agreement are summarized in Table 3. Intraobserver agreement among the 3 readers was “excellent” with

kappa values ranging from 0.907 to 0.950. Interobserver agreement was expected to be relatively lower than intraobserver agreement; however, the former was found to be “substantial” with kappa values ranging from 0.730 to 0.779.

Translational Motion

The mean values of translational motion for each cervical unit are shown in Table 4, and total intervertebral translational motion is shown in Figure 4. On each cervical unit, with increasing degenerative grade at same level, translational motion in Grade II (mild degeneration) tended to increase for segments with discs with Grade III (higher degeneration). However, the translational motion of the segments was observed to significantly decrease in Grade V discs. Significant differences in translational motion were observed between Grades II and III discs at the C7–T1 level and in the total intervertebral translational motion, and between Grades IV and V discs at the C4–C5 and C5–C6 levels and also in the total intervertebral translational motion.

Angular Variation

The mean values of angular variation for each cervical unit are shown in Table 5 and total intervertebral angular motion is shown in Figure 5. No significant difference was observed in the angular variation of each cervical unit in Grades I to IV discs relative to their immediate less degenerative grade at the same level. However, the angular variation of the segments was observed to significantly decrease in Grade V discs. Significant difference in angular variation was observed between Grades IV and V discs at the C4–C5 and C5–C6 levels and in the total intervertebral angular variation.

Contribution of Each Intervertebral Level to Total Angular Mobility

The contribution of each intervertebral level to total angular mobility is shown in Table 6. In Grades I and II discs, the role of C4–C5 and C5–C6 segmental units contributed the majority of total angular mobility of the spine. For Grades III and IV, the motion in segments of C3–C4 and C6–C7 increased, as did the motion in segments C4–C5 and C5–C6. There was significant difference on Grades III, IV, and V compared to Grade I at C3–C4 level. In Grade V discs, the contribution of the C4–C5 and C5–C6 U significantly decreased. Significant

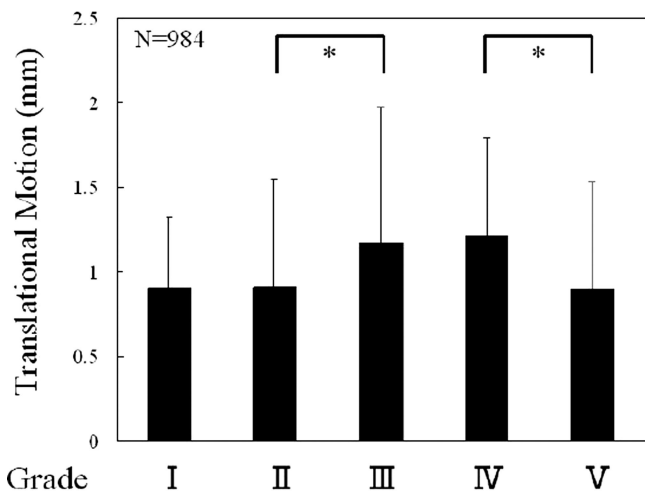


Figure 4. Total intervertebral translational mobility. Compared to immediate less degenerative grade, there were significant differences between Grades II and III and between Grades IV and V at total intervertebral translational motion. * $P < 0.05$ compared to immediate less degenerative grade.

Table 5. Angular Variation for Each Cervical Unit (Degree)

Level	Grade I	Grade II	Grade III	Grade IV	Grade V
C2–C3	6.94 ± 4.72	5.42 ± 4.46	6.94 ± 5.02	6.05 ± 4.27	NA
C3–C4	7.74 ± 9.86	8.02 ± 5.28	10.51 ± 6.07	8.97 ± 5.35	9.04 ± 5.28
C4–C5	11.54 ± 2.54	11.76 ± 7.43	10.07 ± 6.88	10.56 ± 6.65	6.62 ± 4.53*
C5–C6	12.06 ± 7.52	9.59 ± 6.94	10.51 ± 6.16	10.01 ± 7.87	6.27 ± 4.40*
C6–C7	8.51 ± 5.36	9.78 ± 5.36	8.15 ± 5.30	7.68 ± 5.46	7.59 ± 5.07

Values are expressed mean ± SD.

* $P < 0.05$ compared to immediate less degenerative grade at same level.

difference was noted in the contribution of the C4–C5 and C5–C6 levels in Grades V and I discs.

Discussion

Intervertebral disc degeneration is an age-related physiologic process caused by a decrease in the proteoglycan and water concentration in the disc.^{1,2,18} MRI is the most accurate method to evaluate intervertebral disc morphology and to diagnose disc degeneration.^{3,4} Cervicobrachial pain may originate from cervical disc degeneration, which is associated with abnormal instability.^{5–9} However, the natural history of the change in cervical spine motion units following degeneration has not been sufficiently elucidated.

The pathomechanics of a degenerative lumbar spine has been described by Kirkaldy-Willis and Farfan.⁶ They postulated 3 stages of degeneration with different stability and motion conditions. The first stage was a temporary dysfunction phase characterized by early signs of disc degeneration and fibrillation of the articular cartilage of the facet joints. The second stage was the unstable phase characterized by abnormal movement of the spinal units. A decrease in proteoglycan and water concentration in the intervertebral disc weakens the structure, thereby restricting movement between adjacent spinal

units. The disc height reduces, facet capsule loosens, and finally, the joint subluxates. In the last stage, the deformity is assumed to be stabilized by osteoligamentary repair mechanisms. At an advanced stage of degeneration, secondary responses occur in the adjacent osseous and soft tissue structures, causing restabilization of the spine.

Using a cadaver spine, Tanaka *et al*²⁸ demonstrated that the kinematic properties of the lumbar spine are related to disc degeneration. They graded the severity of disc degeneration using MRI and cryomicrotome sections and measured the motion segments under multidirectional loading conditions. Their results demonstrated that greater motion was observed in the higher degeneration stage, *i.e.*, in discs with radial tears of the annulus fibrosus. The disc space collapsed as found in severe degeneration stage resulted in stabilization of the motion units. Axelsson *et al*¹⁴ performed a radiostereometric analysis to investigate changes in intervertebral mobility caused by degeneration. They graded disc degeneration based on conventional radiography and MRI findings. Although they were unable to verify the unstable phase, they concluded that the stabilization stage was apparent when the disc height decreased by more than 50%. Dai⁵ investigated the correlation between disc degeneration and cervical instability. He graded disc degeneration according to T2 signal intensity observed on MRI and measured horizontal and angular instability using conventional lateral flexion and extension radiography. Cervical segmental instability was correlated with a higher degeneration stage.

In this study, we graded cervical disc degeneration using MRI and measured the motion with kinetic MRI. We have demonstrated the changes in translational motion and angular variation for each cervical unit following degeneration. Translational motion changed as the disc degenerated from its normal state to an unstable phase and finally to an ankylosed stage with increased stability. Angular variation significantly decreased in severe degeneration. Although our study focused on the cervical spine, our results support the hypothesis proposed by Kirkaldy-Willis and Farfan.⁶ We believe that kinetic MRI can be applied to clinical practice for defining spinal intervertebral mobility and for determining the treatment mode by studying the progression of disc degeneration, *i.e.*, whether the disc eventually stabilizes or continues to degenerate.

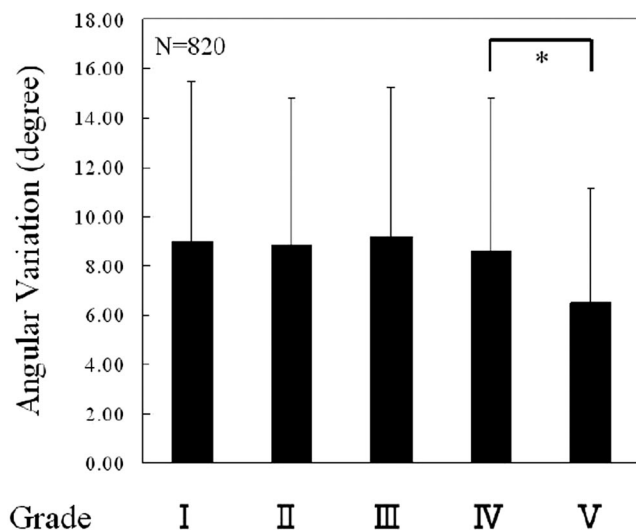


Figure 5. Total intervertebral angular mobility. Compared to immediate less degenerative grade, there was significant difference between Grades IV and V at total intervertebral angular variation. * $P < 0.05$ compared to immediate less degenerative grade.

Table 6. Contribution of Each Level to Total Angular Mobility (Percentage)

Grade	Level C2–C3	Level C3–C4	Level C4–C5	Level C5–C6	Level C6–C7
I	12.35 ± 8.31	11.95 ± 12.65	21.97 ± 5.78	20.61 ± 12.84	15.40 ± 9.86
II	10.46 ± 9.48	14.33 ± 9.37	18.68 ± 9.28	15.84 ± 10.45	16.57 ± 7.65
III	12.32 ± 7.97	18.92 ± 9.88*	18.57 ± 12.00	18.60 ± 10.01	15.85 ± 9.88
IV	12.62 ± 8.71	18.51 ± 10.77*	20.30 ± 10.78	19.47 ± 12.69	16.52 ± 11.78
V	NA	18.89 ± 11.78*	14.54 ± 8.10*	13.42 ± 9.04*	16.53 ± 11.47

Values are expressed mean ± SD.

* $P < 0.05$ compared to Grade I at same level.

According to previous studies,^{2–4} the most commonly affected level is the intervertebral disc at C5–C6 followed by C6–C7 and C4–C5. The C2–C3 level is the least commonly affected. In our retrospective investigation on 164 patients, we observed that the amount of disc degeneration at the C4–C5 and C5–C6 levels was less than that at the other levels in normal discs. In contrast, it was greater at the C4–C5, C5–C6, and C6–C7 levels than at the C2–C3, C3–C4, and C7–T1 levels in severe degeneration. These results prompted us to assume that the C4–C5, C5–C6, and C6–C7 levels contributed the majority to the overall motion of the cervical spine from the early degenerative stage. Using dynamic radiography, Lind *et al*²⁹ evaluated the normal range of motion of the cervical spine in healthy subjects and observed that the greatest proportion of intersegmental flexion-extension motion occurred between the C4–C5 and C5–C6 levels and that a linear decrease in motion occurred with age. Using lateral dynamic radiography, Holmes *et al*³⁰ measured angular motion ranges from C2 to C7 in normal subjects and in those with cervical myelopathy and obtained findings similar to those reported by Lind *et al*.²⁹ Using conventional lateral dynamic radiography in asymptomatic subjects, Lin *et al*¹² demonstrated that the greatest sagittal motion occurred between C4–C5 and C5–C6 and the least motion, at C2–C3. Most studies used active motion for calculating segmental angulation and obtained consistent data. However, these studies did not take into consideration the change in motion that occurs with degeneration. Therefore, we investigated the change in the role of each cervical spine unit during flexion-extension motion caused by degeneration. Our results indicated that the C4–C5 and C5–C6 segmental units contributed the majority of total angular mobility of the spine in normal discs. The contribution of the C3–C4, C4–C5, C5–C6, and C6–C7 U increased in advanced degeneration. The roles of the C4–C5 and C5–C6 U in total angular mobility significantly decreased in severe degeneration.

From these results, we hypothesized that cervical disc degeneration begins at the C4–C5 and C5–C6 levels because these units withstand the maximum load for the overall motion in the early phase. Following degeneration, these segmental units undergo changes from an unstable phase to an ankylosed stage. Many clinical studies have reported increased rates of disc degeneration in the

levels adjacent to spinal fusion.^{31–34} The load of the adjacent levels can be easily assumed to increase, and subsequently, these levels follow the same path. The motion of the adjacent units and their contribution to the overall motion also increases in the unstable phase. Eventually, each cervical unit tends to ankylose with severe degeneration. The mobility of the C4–C5 and C5–C6 U significantly decreases at this stage when compared with the other cervical units and their contribution to the overall motion of the cervical spine significantly decreases.

However, we retrospectively investigated these analyses and did not consider this hypothesis in a persistent model. Thus, using the present investigation as a preliminary study, further prospective research should be undertaken to elucidate the details of the natural history of cervical spine motion following degeneration. Additionally, we believe that kinetic MRI can serve as one of the most useful tools in the prospective research following the investigation of subjects with cervical degeneration.

In conclusion, this study demonstrated the changes in translational motion and angular variation that occur with progressive degeneration. The motion changes with disc degeneration from the normal state to an unstable phase and subsequently to an ankylosed stage with increased stability. We evaluated the contribution of different levels to the changes in overall motion that occurs with degeneration. However, the natural history in cervical spine motion following degeneration has not been elucidated. Further studies are required to provide appropriate treatment methods for the cervical degenerative disease.

■ Key Points

- Kinetic MRI shows the changes of translational motion and angular variation following degeneration.
- The degenerative process affects the mobility of the functional spinal unit, which moves from a normal disc to a more unstable phase with increased mobility with further degeneration. However, as the degeneration enters the later phases and becomes severe, the motion stabilizes to a more ankylosed stage.

- The segments of C4–C5 and C5–C6 U contributed the majority of the total angular mobility of the cervical spine on normal grade. But the roles of C4–C5 and C5–C6 U for total angular mobility significant decreased on severe degeneration.

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The Effects of the Degenerative Changes in the Functional Spinal Unit on the Kinematics of the Cervical Spine

Yuichiro Morishita, MD, PhD,* Shinichi Hida, MD, PhD,† Masashi Miyazaki, MD,*
Soon-Woo Hong, MD, PhD,* Jun Zou, MD,* Feng Wei, MD, PhD,*
Masatoshi Naito, MD, PhD,† and Jeffrey C. Wang, MD*

Study Design. The sagittal kinematics of the cervical spine was evaluated using kinematic magnetic resonance imaging (kMRI).

Objective. To investigate the effect of degenerative changes in the functional spinal unit on cervical kinematics by using kMRI.

Summary of Background Data. Few studies have, thus far, by using MR images, described the contribution of degenerative changes in the functional spinal unit to cervical kinematics; however, the exact cervical kinematics remains uncertain.

Methods. A total of 289 consecutive symptomatic patients underwent dynamic cervical MRI in flexion, neutral, and extension postures. All digital measurements and calculations of the variations in segmental angular motion were automatically performed by an MR analyzer using true MR images with 77 predetermined points marked on each image. Each segment was assessed based on the extent of intervertebral disc degeneration (Grades 1–3) and cervical cord compression (groups A–C) observed on T2-weighted MR images.

Results. The segmental mobility of the segments with severe cord compression and moderate disc degeneration tended to be lower than that of the segments with severe cord compression and severe disc degeneration, and a significant difference was observed in the segmental mobility of the C5–C6 segment. Moreover, in all segments with moderate disc degeneration, the segmental mobility was significantly reduced in the presence of severe cord compression, as compared with no compression. However, in segments with severe disc degeneration, no significant differences were observed between the segmental mobility of the cord compression groups.

Conclusion. Our results suggest that cervical cord compression may cause deterioration of cervical cord function and kinematic changes in the cervical spine. We hypothesize that the spinal cord may potentially protect its functions from dynamic mechanical cord compression by restricting segmental motion, and these mechanisms may be closely related to the intervertebral discs.

Key words: kinematic MRI, functional spinal unit, cervical cord compression, intervertebral disc degeneration, cervical kinematics. **Spine 2008;33:E178–E182**

The cervical spine is the most mobile region of the spine, affording a wide range of motion. The human spine is subjected to large compressive preloads during activities of daily living. The cervical preload approaches 3 times the weight of the head because of the muscle coactivation forces involved in balancing the head in the neutral posture. The compressive preload on the cervical spine increases during flexion, extension, and other activities of daily living, and is estimated to reach 1200 N in activities involving maximal isometric muscle effort.¹

A spinal motion segment is the smallest functional unit of the osteoligamentous spine and exhibits the generic characteristics of the spine. A functional spinal unit (FSU) consists of 2 adjacent vertebrae, the intervertebral disc, and the spinal ligaments (with the exception of the C1–C2 segment). Degenerative changes in the structures of the FSU may ultimately affect the mechanical properties of spinal motion and cause instability and clinical symptoms. Degenerative processes are most prevalent in the C5–C6 segment, followed by C6–C7 and C4–C5.^{2–4}

It may be important to consider the contribution of various factors, such as patient age, gender, neck geometry, degree of degeneration in the cervical spine, history of trauma, and other factors to cervical kinematics. The functional examination of the human spine during flexion–extension along with the measurement of segmental motion in the sagittal plane is a valuable method for analyzing the biomechanics of the human spine. A number of experimental studies on the radiographic and cineradiographic examination of kinematics of the human spine have recently been reported.^{5–11} However, to the best of our knowledge, few reports have thus far, have based results on kinetic magnetic resonance imaging (kMRI), or described the relationship of the degenerative changes and cord compression in the FSU to the kinematics of the cervical spine.

This study examined cervical degenerative changes, such as disc bulging, osteophyte formation, and hypertrophy of the ligamentum flavum, with particular focus on cervical cord compression to evaluate the contributions of these factors to the sagittal plane kinematics of the cervical spine. This study used kMRI to study these variables and their relationship between the effect of degenerative changes in the FSU on cervical kinematics.

From the *Department of Orthopaedic Surgery, University of California at Los Angeles, Los Angeles, CA; and †Department of Orthopaedic Surgery, Fukuoka University, Fukuoka, Japan.

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Address correspondence and reprint requests to Jeffrey C. Wang, MD, Orthopaedic Spine Service, UCLA Comprehensive Spine Center, 1250 16th Street, Suite 745 Santa Monica, CA 90404; E-mail: JWang@mednet.ucla.edu

Materials and Methods

From February 2006 to May 2007, 289 symptomatic patients (125 men and 164 women) with an average age of 44.0 years (range, 16–93 years) were examined. The subjects consisted of consecutive patients who had neck pain with or without neurogenic symptoms induced by cervical spondylosis. All patients underwent cervical kMRI; scanning was performed with dynamic motion of the cervical spine, including flexion (-40°), neutral (0°), and extension (20°) postures. None of the subjects had previously undergone spinal surgery. The Institutional Review Board approved the study.

MRI Technique

MRI of the cervical spine was performed on a 0.6 Tesla MRI scanner (Upright Multi-Position; Fonar Corp., NY, NY) using a flexible surface coil. The imaging protocol included sagittal T1-weighted spin-echo sequences [repetition time (TR)/echo time (TE), 671/17 milliseconds; slice thickness, 3.0 mm; field of view, 24 cm; matrix, 256×200 ; and number of excitations (NEX), 2] and T2-weighted fast spin-echo sequences (TR/TE, 3432/160 milliseconds; slice thickness, 3.0 mm; field of view, 24 cm; and NEX, 2). All sequences were acquired without fat saturation.

MRI Analysis

The data obtained from the MR images were recorded on a computer for subsequent measurements, and all calculations were automatically performed on true MR images by an MR analyzer. Sagittal MR images were analyzed in 3 positions—flexion, neutral, and extension. For digitization, 77 points were marked on the images by spine surgeons (C3–T1: 6 points on each vertebral body, 2 on each pedicle, and 2 on the spinal canal diameter at each intervertebral disc level; C2: 1 point on the tip of the odontoid process and 6 on the vertebral body; C1: 4 points on the anterior, superior, and inferior surfaces of the anterior tubercle and the lower end of the spinous process; and the occiput (Oc): 2 points on the anterior and posterior baselines) (Figure 1).

The sagittal angular motion was measured for each segment at 5 cervical intervertebral disc levels—C2/3, C3/4, C4/5, C5/6, and C6/7. We defined the total sagittal motion of the cervical spine as the absolute total of the individual sagittal angular motions ($C2/3 + C3/4 + C4/5 + C5/6 + C6/7$) in degrees, and the contribution of each segment to the total angular mobility of the cervical spine between flexion and extension as percent segmental mobility = (sagittal angular motion of each segment in degrees)/(total sagittal angular motion in degrees) \times 100.

Assessment of Degenerative Changes in the Cervical Spine

A comprehensive grading system for cervical disc degeneration was obtained by modification of the previously reported system of classification of cervical intervertebral disc degeneration that was based on the degenerative changes in the FSU.^{12–16} Accordingly, neutral-position T2-weighted sagittal images of 1445 cervical intervertebral discs of 289 subjects were classified into 3 grades (Table 1) by the primary author and were judged eligible for inclusion into the study.

Assessment of Cervical Cord Compression

We estimated cervical cord compression in each segment by examining neutral-position T2-weighted sagittal images. We regarded cervical cord compression as the obliteration of the subarachnoid space resulting from compression caused by disc herniation, osteophyte formation, or hypertrophy of the ligamentum flavum. Cervical cord compression in each segment

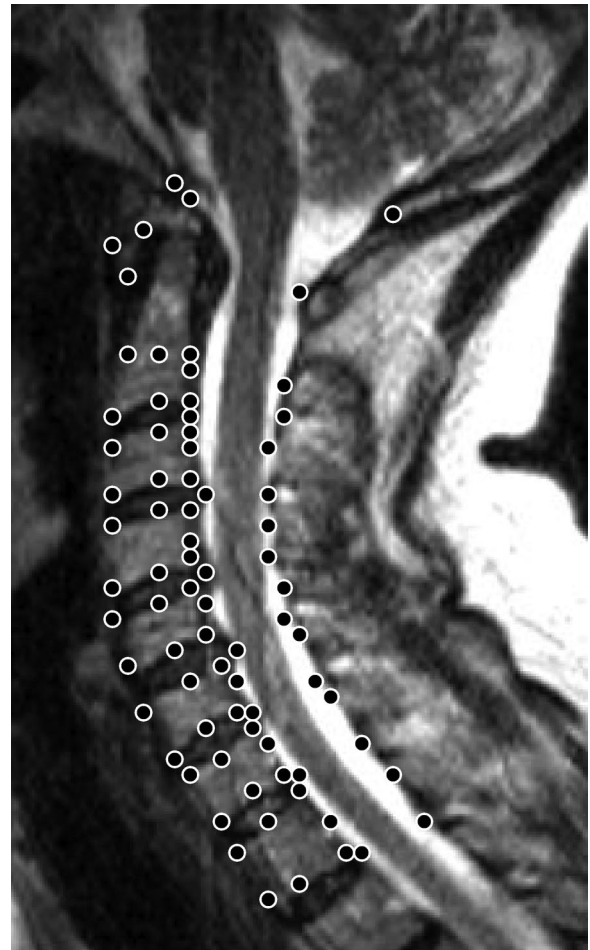


Figure 1. Seventy-seven points were marked for digitization on the sagittal images.

was rated on a 3-point scale (range, 0–2) in which 0 indicated no cervical cord compression, 1 indicated anterior or posterior cervical cord compression not affecting cord alignment, and 2 indicated anterior or posterior cervical cord compression affecting cord alignment. Based on this scale, we classified individual segments into 3 groups: group A, a total of 0 points for each segment; group B, a total of 1 point for each segment; and group C, a total of more than 2 points for each segment. We excluded the C2/3 segment because a few subjects showed cervical cord compression at this level.

Statistical Analysis

Mann-Whitney *U* test was used for statistical analyses. A *P* value of less than 0.05 was considered statistically significant.

Table 1. The Grading System for Cervical Intervertebral Disc Degeneration

Grade	Nucleus Signal Intensity	Disc Height	Structure of FSU
1	Hyperintense	Normal	Without disc herniation
2	Intermediate/hypointense	Normal/decreased	With/without disc herniation
3	Hypointense	Decreased/collapsed	With disc herniation/osteophyte

Table 2. The Percent Segmental Mobility for Each Grade of Cervical Intervertebral Disc Degenerative Change in Each of the Segmental Cervical Cord Compression Groups

Grade	Group								
	A			B			C		
	No.	Age	Mean (SD)	No.	Age	Mean (SD)	No.	Age	Mean (SD)
C3/4									
1	83	38.7	17.32 (10.33)						
2	139	45.1*	21.16 (11.05)†	30	44.1	22.96 (11.47)‡	14	47.6	15.66 (11.38)‡
3	5	49.8*	25.53 (10.45)‡	9	51.9	29.36 (10.49)	9	56.2‡	23.60 (9.04)
C4/5									
1	60	35.7	23.89 (12.27)						
2	118	44.1*	27.04 (9.84)‡	30	46.4	25.29 (8.10)	12	45.9	17.23 (10.66)†
3	21	47.5†	26.30 (10.41)	23	46.4	26.87 (13.67)	24	53.8†	20.77 (11.91)
C5/6									
1	31	31.9	21.99 (12.90)						
2	75	41.9*	24.27 (12.17)	39	44.3	22.36 (9.22)	8	45.0	11.53 (5.05)*‡
3	33	46.1*	19.99 (10.82)	53	49.1†	20.00 (11.71)	50	48.3	19.94 (13.07)
C6/7									
1	90	37.2	18.76 (10.02)						
2	89	44.1*	19.00 (9.86)	23	45.3	17.52 (9.54)	7	49.1	12.27 (5.04)‡
3	23	49.3*	18.57 (12.69)	36	49.6	16.75 (11.09)	21	52.8	18.26 (14.45)

* $P < 0.001$; † $P < 0.01$; ‡ $P < 0.05$.

■ Results

The percent segmental mobility for each grade of cervical intervertebral disc degenerative change in each of the segmental cervical cord compression groups is shown in Table 2.

In group A, the grade of degenerative changes in the intervertebral discs increased significantly with an increase in age. With regard to the C3–C4 segment, the average percent segmental mobility at C3–C4 gradually increased with an increase in the grade of degenerative changes in the intervertebral discs, and when compared with Grade 1 changes, significant differences in percent segmental mobility were observed with both Grade 2 and Grade 3 changes ($P < 0.01$ for Grade 2 and $P < 0.05$ for Grade 3). With respect to the C4–C5 segment, there was a significant increase in the average percent segmental mobility at C4–C5 with Grade 2 changes ($P < 0.05$); moreover, percent segmental mobility with Grade 3 changes was almost identical to that with Grade 2 changes. Regarding the C5–C6 segment, the average percent segmental mobility at C5–C6 showed a slight increase with Grade 2 changes and a slight decrease with Grade 3 changes, when compared with Grade 1 changes; however, no significant differences were observed between these values. Regarding the C6/7 segment, the average percent segmental mobility at C6–C7 was almost identical in all groups. In group B, all segments with Grade 3 changes except C4–C5 tended to be associated with a higher age, when compared with the segments with Grade 2 changes; further, only C5–C6 showed a significant difference with respect to age between the groups with Grade 2 and Grade 3 changes. In group B, the average percent segmental mobility at C3–C4 was significantly lower with Grade 2 changes than with Grade 3 changes ($P < 0.05$). With respect to the other segments in group B, the average percent segmental mobilities with Grade 2 and

Grade 3 changes were almost identical. In group C, all segments with Grade 3 changes tended to be associated with a higher age when compared with the segments with Grade 2 changes, and significant differences with respect to age were observed between Grade 2 and Grade 3 changes in both C3–C4 and C4–C5 segments. With respect to all segments, the average percent segmental mobility tended to be lower with Grade 2 changes than with Grade 3 changes; further, a significant difference in the average percent segmental mobility was observed only in C5–C6 ($P < 0.05$).

Regarding Grade 2 changes, in all segments, there were no significant differences between the groups with respect to age. The average percent segmental mobilities of all segments in group B were almost identical to those in group A; however, the average percent segmental mobilities of all segments in group C were significantly lower than those in group A ($P < 0.05$ for C3–C4, $P < 0.01$ for C4–C5, $P < 0.001$ for C5–C6, and $P < 0.05$ for C6–C7). In group C, Grade 3 changes in only C4–C5 were associated with a significantly higher age. No significant differences in the average percent segmental mobilities were observed between the groups with respect to all segments with Grade 3 changes.

■ Discussion

Many studies have described normal or abnormal cervical kinematics by using different imaging techniques and measurements.^{5–11,17–21} Overall, segmental motion of the cervical spine is the least at the C2–C3 level and greatest at the C4–C5 and C5–C6 levels.

The earliest lesions related to degenerative processes of the human spine are thought to occur in the intervertebral disc. Intervertebral disc degeneration typically begins to appear in the second decade of life in men and in the third decade in women, and more than 50% of the

middle-aged population shows some evidence of cervical spondylosis.²² Because of altered mechanical function of the disc, degenerative changes also begin to occur posteriorly in the facet joints. This degenerative process of the FSU can lead to localized segmental instability or stiffening within different levels of an individual spine.²³ Analysis of segmental motion of the cervical spine may help in detecting degeneration or damage within the spine.

Regarding the effect of dynamic motion on the cervical spinal cord, the cervical cord shortens and its cross-sectional area increases during extension of the cervical spine; however, during flexion, it stretches, leading to increased axial tension.²⁴ These mechanical stresses on the cervical cord as well as static factors, such as disc herniation, osteophyte formation, and hypertrophy of the ligamentum flavum that result from degenerative changes in the FSU, contribute to the pathogenesis of cervical spondylitic myelopathy.²⁵

Chen *et al*²⁶ reported that increased segmental angular motion may reduce the sagittal diameter of the spinal canal and lead to spinal canal stenosis associated with disc bulging and hypertrophy of the ligamentum flavum. In contrast, Mihara *et al*²⁷ focused on canal stenosis at the C3–C4 level and reported that in elderly patients with cervical spondylitic myelopathy due to canal stenosis at the C3–C4 level, the C3–C4 segmental angular motion was significantly greater than that in younger subjects or in the elderly healthy population. They hypothesized that an age-related reduction in the mobility of the lower cervical segments may promote mechanical stresses on the upper cervical segments, leading to canal stenosis at the C3–C4 level. However, they discussed only the process of cervical spinal canal stenosis in relation with the degenerative changes in the cervical spine. We presumed that the next change in cervical kinematics might occur after the formation of cervical spinal canal stenosis with degenerative changes in the cervical spine.

It is generally accepted that there are 3 separate stages of clinical manifestations of degenerative changes in the intervertebral discs; these include temporary dysfunction, an unstable phase, and stabilization with progression of the degenerative changes.^{28,29} In our study, in all segments within all the compression groups, the degenerative changes in the intervertebral discs tended to progress with age. However, in C3–C4 and C4–C5 with no cervical cord compression, the contribution of each segment to total cervical mobility increased with progression of the degenerative changes in the intervertebral discs from Grade 1 to higher grades. We felt that the reliability of these findings was low since there were few subjects in whom the C3–C4 and C4–C5 segments had Grade 3 changes. In the other segments with no cervical cord compression, particularly the C5–C6 segment, segmental mobility showed an unstable phase and stabilized with progression of the degenerative changes in the intervertebral discs; however, no significant differences in segmental mobility were observed in these segments.

On the other hand, in segments with cervical cord compression, particularly severe cord compression, segmental mobility tended to show lower values in segments with moderate intervertebral disc degeneration than in those with severe degeneration; moreover, a significant difference was observed in the segmental mobility at C5/6. Moreover, in all segments with moderate disc degeneration, there were no significant differences between the compression groups with respect to age, and the segmental mobility was significantly reduced in the segments with severe cord compression when compared with those with no cord compression. These results suggest that cervical cord compression greatly affects the sagittal segmental motion of the cervical spine only if there is sufficient intervertebral disc height and flexibility. We hypothesize that the spinal cord may shift horizontally to prevent lesions that develop due to cord compression. However, in severe cord compression that affects spinal cord alignment and causes cord impingement, the spinal cord cannot shift away and escape compression and may be affected by restriction of segmental motion. Cervical cord compression may result in not only deterioration of the cervical cord function but also kinematic changes in the cervical spine. The spinal cord may protect its function from dynamic mechanical cord compression by restricting segmental motion.

However, in segments with severe intervertebral disc degeneration and decreased height or collapse of the intervertebral disc, no significant differences were observed between the segmental mobilities of the cord compression groups. This result suggests that when the intervertebral discs are stiffened due to severe degenerative changes such as disc height loss or osteophyte formation, sagittal segmental motion of the cervical spine is only mildly affected by cervical cord compression. Moreover, we hypothesized that the mechanisms for protecting the spinal cord may be closely related to the intervertebral discs. Deterioration in intervertebral disc function may lead to deterioration in the mechanisms for protecting the spinal cord.

However, some issues remain unanswered even in the current study. We did not discuss the relationship between cervical kinematics and other factors such as gender, age, cervical alignment, and clinical manifestations. Therefore, using the current investigation as a pilot study, further research using larger patient populations may help to resolve several unclear results obtained from this study; moreover, the details of the relationship between cervical kinematics and the degenerative changes in the FSU can be clarified further.

■ Key Points

- By using kinematic MR images, a total of 1445 functional spinal units of 289 symptomatic subjects were examined for intervertebral disc degeneration and cervical cord compression.

- In segments with severe cord compression and moderate disc degeneration, the segmental mobility tended to have lower values than in those with severe cord compression and severe disc degeneration.
- In all segments with moderate disc degeneration, the segmental mobility was significantly reduced in the presence of severe cord compression when compared with no compression; however, in segments with severe disc degeneration, no significant differences were observed between the cord compression groups with regard to segmental mobility.
- Our results suggest that cervical cord compression may result in not only deterioration of cervical cord function but also kinematic changes in the cervical spine.
- We hypothesize that the spinal cord may potentially protect its functions from dynamic mechanical cord compression by restricting segmental motion, and these mechanisms may be closely related to the intervertebral discs.

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