MRI-Based Morphological Predictors of SPECT Positive Facet Arthropathy in Patients with Axial Back Pain

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INTRODUCTION: A major barrier to understanding facetogenic low back pain has been the lack of radiographic diagnostic criteria. This study investigates the correlation between radiographic findings on MRI and SPECT in patients found clinically to have facetogenic axial back pain.

METHODS: 31 patients with severe axial back pain underwent lumbar MRI and SPECT. 230 facets were identified and were graded from 1 to 4 using synovial area, size, cartilaginous discontiguity, osteophytic overgrowth, and joint space obliteration. 29 "hot" joints were identified on SPECT. MRI features of 230 lumbar facets were correlated with SPECT results.

RESULTS: Four basic morphological patterns were identified on basis of synovial appearance on MRI—Light, Mottled, Narrowed, and Oblitered—and formed the basis for the grading 1 ~ 4 respectively (sensitivity for "hot facet" 0.93). The mottled group had 0.90 specificity ($P = 0.0001$). Osteophytic overgrowth demonstrated 0.94 specificity ($P = 0.0004$). Facet hypertrophy was not associated with increased tracer uptake.

DISCUSSION: We identify four types of synovial architecture on T2WI MRI with overall high sensitivity for predicting SPECT positivity. These four grades likely represent a continuum of facet degeneration, from a normal to obliterated joint. One particular subtype, Grade 2, demonstrated a high specificity for SPECT and synovial fluid increase suggestive of inflammation. Facet hypertrophy was not predictive of bone scan positivity, perhaps suggesting the protective nature of a hypertrophied facet.

CONCLUSION: Synovial abnormalities correlate with SPECT findings and a grading scale is proposed delineating the degeneration of a lumbar facet over time. A subtype of SPECT (+) inflamed joint is proposed. Further studies will be needed to improve our understanding of the natural history of the lumbar facet.

KEY WORDS: arthropathy, arthritis, facet, low back pain, magnetic resonance imaging, SPECT, spine

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INTRODUCTION

The diagnosis and treatment of axial back pain has been problematic due to the large number and diversity of potential pain generators in the lumbar spine. While the contemporary literature focuses primarily on the intervertebral disc as a pain generator, it is increasingly apparent that facet joints also play a major role. Little is known about the pathogenesis of facet arthrosis and how it relates to overall segmental degeneration (3, 11, 18, 19, 21, 22, 24, 30, 32, 33, 34, 35, 36, 46, 55, 57, 59, 62, 73) as well as segmental instability (17). What is known stems largely from studies of anterior column degeneration (6, 17, 38, 66). Most spine surgeons assume a causative relationship between anterior column failure and subsequent posterior element decompensation with progressive segmental instability (1, 7, 17, 31, 41, 50, 67, 77).

One of the major barriers to understanding facetogenic back pain has been the lack of good radiographic diagnostic criteria (16, 19, 20, 28, 69, 72). This is complicated by the frequent clinical observation that a large percentage of asymptomatic patients are found incidentally to have advanced facet joint degeneration, an often-subjective observation that has led some clinicians to question whether facetogenic pain is even a valid entity. These patients have large, hypertrophic facets which are clearly morphologically abnormal on MRI or CT scans but no complaints of back pain. Of course, abnormal morphology may not necessarily reflect underlying clinical pathology.

Clinical correlation of spinal facetogenic disease to radiographic findings is lacking at the present time. Several investigators have attempted to radiographically classify facet degeneration independent of clinical history (10, 14, 16, 17, 19, 20, 47). In describing the radiographic findings of facet disease, previous authors have focused on bony or soft-tissue changes that appear abnormal but are of unknown clinical significance. Once again, abnormal morphology may not necessarily reflect underlying pathology. Grogan and colleagues established two 4-point classifications, one based on the amount of peri-articular osteophyte formation, and the other, cartilage degeneration seen on MRI (16, 20). Using Grogan's classification systems, Fugiwara and colleagues attempted but were inconclusive in relating facet degeneration to disc disease but noted that degeneration of both disc and facet contributed to instability of the segment (16). Weishaupt and colleagues tested the agreement between MR and CT—the radiologist's ability—to objectively assess for bony changes and joint space narrowing in the lumbar facet joints; he showed that CT and MR were consistent in demonstrating morphological aberrances in the facet joint (69). Likewise with Xu and colleagues who compared MRI to CT for visualizing soft tissue abnormalities such as synovial protrusions and pathology of the facet joint capsules (72). In an era of uncertainly regarding the role of the facet in stability and pain, it is difficult to find an agreement between facet morphology and its clinical significance.

One approach to determining the degree of clinically-significant degeneration based on morphological imaging is to use functional techniques for diagnosing arthropathy and joint inflammation (12, 13). Radionuclide modalities are commonly employed for the identification of such musculoskeletal abnormalities (2, 5, 37). By virtue of its ability to narrow the field of interest, single photon emission computed tomography (SPECT) is more sensitive than planar scintigraphy (9, 10, 27) and has been used for diagnosing inflammatory joint diseases, such as in temporomandibular joint inflammation, sacroiliitis, rheumatoid arthritis, crystal arthropathy, and osteoarthritis (2, 5, 9, 27, 58, 75). SPECT is increasingly employed to detect synovial joint disorders (5, 9), and has been highly reliable for diagnosing symptomatic chronic and acute injuries to the synovial soft tissues (37, 65, 76). The lumbar facet joints, being truly synovial in nature, have also been evaluated using SPECT, and multiple investigators have advocated the use of this highly sensitive modality for diagnosing facetogenic pain. In the study by Holder, et al., high resolution SPECT bone scans proved to be 100% sensitive and 71% specific for a clinical diagnosis of facet disease (23). Similarly, in the study by Dolan, et al., positive SPECT studies resulted in a 95% response rate to targeted injection therapy (14).

This study investigates the correlation between radiographic findings on MRI, an excellent tool for analyzing anatomic detail (54, 63), and SPECT radionuclide studies, a highly sensitive test for abnormal musculoskeletal metabolism, in patients found clinically to have facetogenic axial back pain. Using this methodology, it is hoped that anatomic changes associated with symptomatic facet arthropathy—an inflamed facet—can be identified, with particular attention towards the cartilaginous and synovial structures.

MATERIALS & METHODS

Patient Population & Radiographic Studies

The patient population included 431 patients with severe axial back pain presenting to the University of Southern California Department of Neurosurgery Spine Center between 2000 and 2005. All patients with spondylolisthesis, scoliosis, neoplasia, or infectious etiologies of back pain were excluded. All patients with a diffuse disk bulge or significant protrusion and leg pain were excluded. postoperative facet sites were excluded. A total of 31 patients were identified (16 men). All included patients underwent high-resolution single-photon emission computed tomography (SPECT) imaging by standardized spine-bone protocol (28 milliCurie intravenous injections of ^{99}Tc-MDP; ADAC Vertex dual head scanner, Phillips Medical Systems, BothelWA).

25 patients had 29 "hot lesion" showing abnormal radionuclide uptake in at least one facet joint. Interpretation of the level of facet joint involvement was made by a nuclear medicine radiologist who had access to concomitant X-rays and MRI images to account for any abnormalities in segmentation, which could confound level designation. Abnormal radionuclide uptake was graded on a 4-point scale. Cervical and thoracic facet joints were omitted in the study to reduce confounding factors pertaining to facet shape and role at different levels of the spine (29, 33, 40, 49, 61, 68, 71).

The most recent lumbar magnetic resonance (MR) images taken within 10 months of SPECT scanning were then analyzed. Lumbar imaging consisted typically of the L1 to S1 levels performed on a 1.5 Tesla magnet. Each MR image was transferred to digital format and enhanced and magnified with Adobe Photoshop 7 (Adobe Systems Incorporated, San JoseCA). Qualitative features were evaluated on axial MR images, including (a) synovial and cartilaginous discontinuity, (b) variation of signal intensity of the synovial space on T2 weighted MRI, (c) patterns of bone deformation, (d) protrusion of synovium beyond the capsule, (e) overall geometry of the facet joint, and (f) cupping osteophyte formation in the lateral joint. Quantitative features were evaluated using ImageJ software (National Institutes of Health, BethesdaMD), including (g) asymmetry in facet size between the right and left sides, (h) the synovial area, (i) angle of joint alignment in relation to the endplate, (j) degree of joint space narrowing, and (k) lateral & medial synovial content. Numbers were randomly assigned to each facet joint and each facet joint was graded on the above features (a–k). The investigator grading the facet joint was blinded to the results of the SPECT scan. All statistics were performed with the use of Analyze-It software (International Oncology Network, BaltimoreMD). Two-tailed p values were calculated using Fisher's exact test.

Qualitative Facet Joint Features

Four basic morphological patterns were identified on basis of synovial appearance on MR. Based on these synovial appearances, joints were characterized as either Light (L)MOtled (M), Narrowed (N), or Obliterated (O) on axial T2 weighted MRI images (*Table 1*). This generally reflected a four-step progression

TABLE 1. Morphological variations of lumbar facet synovial joint on axial T2W MR images

Grade	Synovial Morphology	Synovial signal on T2WI	Evidence of material inside synovium or cartilage disruption	Cartilage Thickness	Presence of of synovial fluid	Prevalence (see Fig 5)
1	Light	Bright	No	Full	Yes	31%
2	Mottled	Bright	Yes	Full to Thin	Yes Often Full	18%
3	Narrowed	Dark	No	Full to absent	Yes	21%
4	Obliterated	Absent	No	Full to absent	No	30%

* a (b) is added next to the Grade to signify the presence of bony osteophytic overgrowth.

in joint degeneration, ranging from a normal healthy (Light) appearance to an obliterated one. In determining this classification, it was essential that each synovial appearance was clear on a routine MRI to non-radiologists.

Light synovium was bright with a thick contiguous hypointense line at the osteochondral junction representing normal cartilage. No central synovial space incongruencies were noted in the Light group, and these were essentially normal joint spaces as shown in *Figure 1a*. The Mottled group was significant for obvious defects of cartilaginous contiguity and dark regions within the synovial joint interspersed within a bright synovial space. The synovium was full in signal intensity and area if not seemingly in excess of fluid. Subligamental cysts or fluid were sometimes noted along the outline of the facets (*Fig. 1b*). The Narrowed synovial spaces had a markedly decreased width in the synovial space between the cartilaginous borders (*Fig. 1c*). Obliterated facets demonstrated no synovial space on MRI (*Fig. 1d*).

MR images were independently examined for discontiguities in the joint capsule as evidenced by synovial protrusion beyond the bony margins, which was termed a "synovial hook" for its scythe-like appearance around the articular process. Radiographic MR visualization and determination of synovial protrusion followed the description defined by Xu and colleagues (72).

'Bony hooks'—defined as abnormal and irregular calcifications of the medial or lateral joint surface consistent osteophytic overgrowths—were noted as well (*Fig. 2a* and *b*). The presence of bony hooks or osteophytic overgrowth was marked with a 'b' by its synovial grade (*Table 1*). Hence, a facet joint with cartilaginous abnormalities and osteophytic changes would be graded 2b. A facet joint with narrowed joint space and osteophytic overgrowth would be 3b.

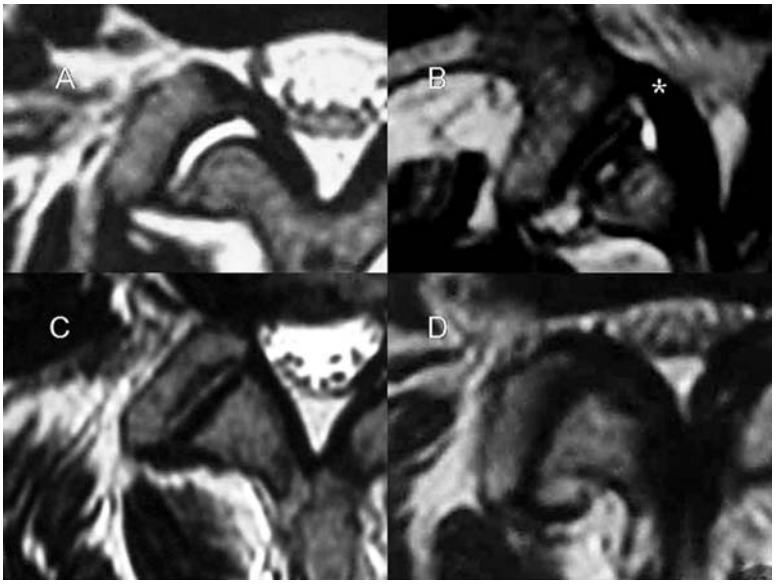

FIGURE 1. *T2WI axial MR of lumbar facet joints Grade 1 through 4. These joints were graded on a four-point scale using cartilaginous discontiguity, joint space narrowing, osteophytic overgrowth as key differentiating factors. (*A*) Grade 1* Light *synovial group, this facet joint contains bright synovial content with a contiguous thick rim of cartilage on either side of the joint surface. The capsule is undisturbed. (*B*) Grade 2* Mottled *synovial group, the synovial space is* full in appearance *and contains bright synovial fluid interspersed with dark lines, likely cartilaginous breakdown material. Articular cartilage discontiguity is present as well. Note the subligamental cyst fluid lateral to the ligamentum flavum—this deposition of fluid was often noted in Grade 2 facets (*) (*C*) Grade 3* Narrowed *synovial space group, the synovial spaces are markedly* narrowed *in this facet joint. The synovial space is darker in appearance on T2WI when compared with Grade 1; (*D*) Grade 4* Obliterated *synovial space group, no synovial space is noted in this facet.*

Quantitative Facet Joint Features

T2 weighted axial MR digitized images were standardized using the image rulers for area calculations. The synovial joint space, the size of the inferior facet, the size of the superior facet, and the angle of the facet joint to the sagittal plane were measured. Area of the inferior (lateral) and superior (medial) facets were measured excluding the cartilaginous surfaces and synovium.

In measuring superior facet area on axial MR, a line was drawn from the center of the lamina where it abuts the central canal to the lateral margin of the medial facet. The bony area bordered by this line and the cartilaginous surface was arbitrarily defined as the area of the superior facet. *(Fig. 4*). Overall facet joint size was calculated as the sum of the inferior facet, superior facet, synovial, and cartillaginous areas.

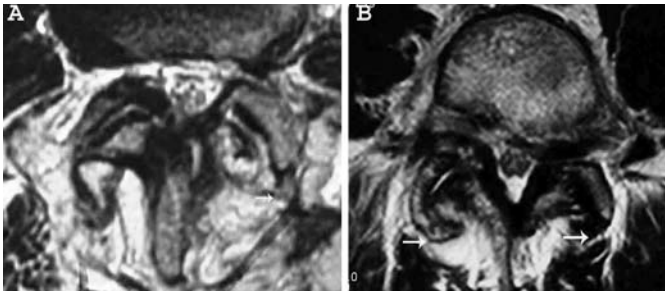

FIGURE 2. *Synovial and Bony protrusions noted in MRI (*A*) T2WI axial MR of two lumbar facet joints with synovial protrusion on the left and synovial extrusion on the right joint. Both types of synovial protrusions were termed* synovial hooking. *The right facet is Grade 3 and the left facet is Grade 2b, the "b" denoting osteophytic overgrowth (*arrow*). Note the exuberant quantity of fluid accumulation in the Grade 2 facet; (*B*) two lumbar facets joints are noted, exemplifying different degrees of lateral osteophytic overgrowth, or,* bony hooking. *The right facet joint (Grade 3b) has significantly more* bony hooking *than the left (Grade 4b).*

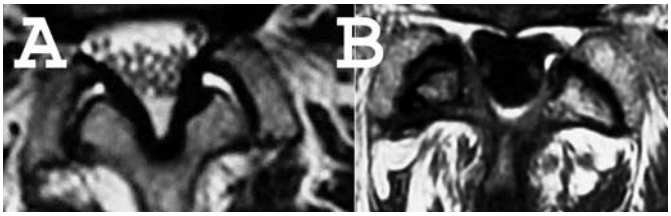

FIGURE 3. *T2WI axial MR of two lumbar facet joints compared for overall geometry. Note the smooth round contour of facet joints in (*A*) versus the rhomboid or box-like contour of (*B*). Facet joints from right to left in (*A*) are Grades 1 and 2 respectively. Note the increased fluid amount in Grade 2 facets compared to Grade 2. Facet joints from right to left in (*B*) are Grades 3b and 4 respectively.*

RESULTS

Qualitative Findings

A total of 230 "cold" and "hot" lumbar facet joints were analyzed. Comparisons were thus made between those facets with and without increased radiotracer uptake. Using the L, M, N, O classification of synovial joint spaces 31% of all facet joints, positive or negative, were light, 18% were mottled, 21% were narrowed, and 30% were obliterated. Taking all abnormal synovial appearances together as a group (mottled, narrowed, or obliterated) resulted in a sensitivity of 0.93 for SPECT uptake (Fisher's exact test, two-tailed p-value = 0.0029). However, specificity was lacking (0.35). Of the SPECT positive facets 4 were light, 17 were mottled, 5 were narrowed, and 3 were obliterated (*Table 2*). The mottled group had a high specificity at 0.90 for predicting a positive SPECT result ($P = 0.0001$) but was less sensitive (0.59). The Mottled group had 5.6 times the number of 'hot' facet joints when compared with the Light group. *Table 2* shows the sensitivity and specificity of the four groups with corresponding p values (*Table 2*).

Fifteen of the 230 facet joints demonstrated synovial protrusion outside its normal margins on axial T2 weighted MRI (6.5% of all facet joints). Such protrusion was contiguous with the facet joint proper and was termed a "synovial hook" for its morphological characteristics. Synovial hooking was not sensitive (0.13) but was specific (0.94) for positive SPECT ($P = 0.126$). Of the 15 facets with synovial protrusion, 12 were Mottled, and 3 were Narrowed (*Figure 5*).

Bony cupping and osteophytic overgrowth medially and laterally around the facet joint was noted on 22 facet joints (9.6%) and was termed "bony hook." Bony hooking was not sensitive (0.31) but was specific (0.94) for positive SPECT ($P = 0.0004$).

TABLE 2. Sensitivity and specificity of morphogenic markers for SPECT (+) facets

	Sensitivity	Specificity	Predictive Value Negative	Predictive Value Positive	p-value*
Synovial Appearance					
Light	0.04	0.59	0.04	0.61	0.0001
Mottled	0.61	0.90	0.54	0.92	<0.0001
Narrowed	0.10	0.75	0.14	0.69	0.0383
Obliterated	0.35	0.69	0.18	0.85	0.0001
Excluding Light	0.93	0.35	0.21	0.94	0.0029
Space narrowing < 0.137 cm2	0.54	0.44	0.84		
Facet appearance					
Synovial Hook	0.13	0.94	0.42	0.86	0.126
Bony Hook	0.31	0.94	0.50	0.85	0.0004
Facet widest diameter	0.5	0.5	0.16	0.84	1.0
Facet area > 2.35 cm2	0.46	0.53	0.16	0.84	1.0

* two-tailed p values calculated using AnalyzeIt software Fisher's exact test method

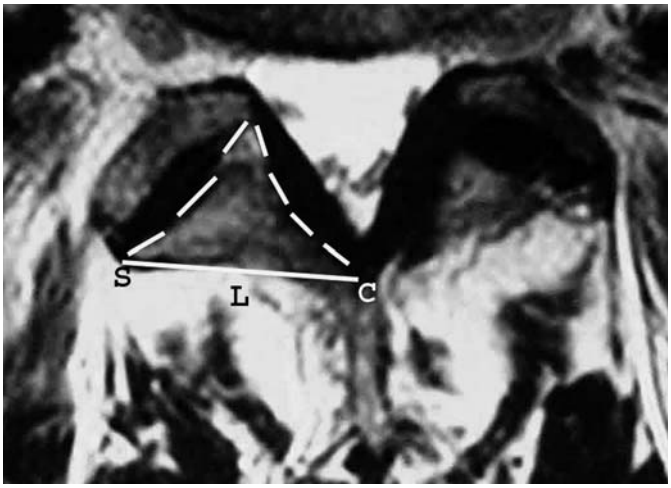

FIGURE 4. *Measurement method for facet area. Noted here are two Grade 4 facets. In order to measure the area of the superior facet in a standardized manner, arbitrary and consistent markers were used. A line* (L) *was drawn from the center of the lamina* © *where it touches the central canal to the lateral margin of the medial facet* (S). *The bony area bordered by this line L and the dotted lines was defined as the* area of the superior facet.

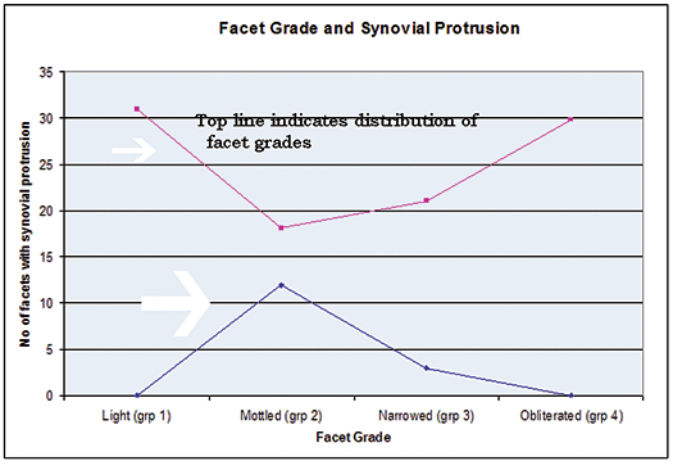

FIGURE 5. *Facet Grade and synovial protrusion.* Small arrow *indicates the distribution of each grade of facet over all facets (%).* Large arrow *notes the increased synovial protrusions observed in Grade 2 facets when compared to other facets.*

Quantitative Findings

The average facet joint area was 2.35 cm^2 excluding the synovial space and 2.48 cm^2 including the synovial space. Average synovial space was 0.137 cm^2. 30% of synovial spaces were obliterated. The average widest diameter of the facet joint (longest measurable dimension of the facet joint on axial MR) was 2.25 cm.

Facet enlargement over the average size correlated poorly with positive SPECT results (sensitivity 0.53, specificity 0.54). Synovial space narrowing below 0.137 cm^2 correlated poorly as well (sensitivity 0.54, specificity 0.44). Absence of synovial space demonstrated sensitivity of 0.35, and specificity of 0.69.

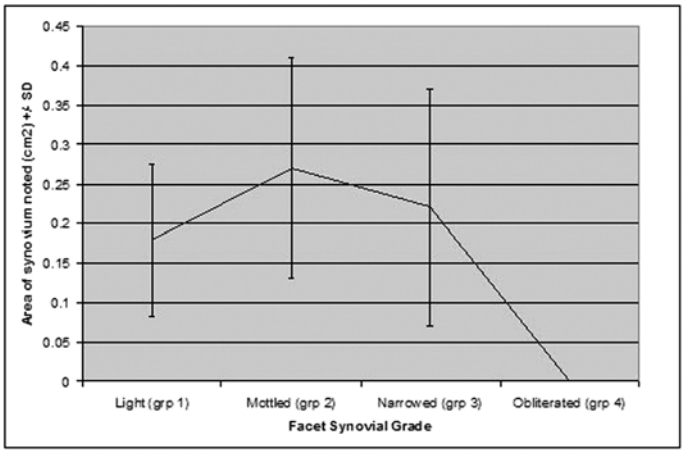

FIGURE 6. *Facet Grade and synovial area. The mean synovial area and standard deviation are compared between Grades 1 through 4. Grade 2—the Mottled Group demonstrates an increase in synovial fluid area when compared to the other facets. Such increase in fluid accumulation is also visible to the observer on MRI* (Fig. 1B).

Synovial space area demonstrated increase in T2W intensity content—presumably fluid—in the Mottled Group above the other groups (*Fig. 6*).

Facets were compared quantitatively left from right. Asymmetry of size right from left correlated poorly (sensitivity 0.26, specificity 0.82). Positive predictive value of predicting SPECT positive results using gross facet asymmetry was 26%.

Comparison Between Qualitative & Quantitative Findings

The Narrowed group demonstrated increased area over the other groups by a factor of 1.06 to 1.12 (*Fig. 7*).

The average facet joint size on axial MR for the Light group was 2.27 $cm^2 \pm 0.642$ SD. Likewise, average facet joint sizes for Mottled were 2.263 $cm^2 \pm 0.584$ SD, for Narrowed 2.54 $cm^2 \pm 0.562$, and for Obliterated 2.38 $cm^2 \pm 0.51$ SD.

DISCUSSION

The lumbar facet syndrome was first described as a clinical entity by Ghromley in 1933 (18). Since then, several advances have been made in our understanding of this disease entity. Many hypotheses have been generated to explain the natural history of facet degeneration, focusing on the role of antecedent anterior column failure in accelerating subsequent posterior element decompensation (15, 17, 19, 31, 38, 42, 43, 45, 67, 70). However, clinicians treating patients with back pain also realize that facet pain can occur in the absence of significant disc degeneration (39, 59, 74, 77).

The facet joint, unlike the intervertebral disc, is a true synovial joint. It is composed of two articular surfaces, an outer capsule formed by collagen and ligaments, and an inner synovial lining. The joint produces synovial fluid, the prime lubricant for the joint and the nutritional source for the joint surface cartilage.

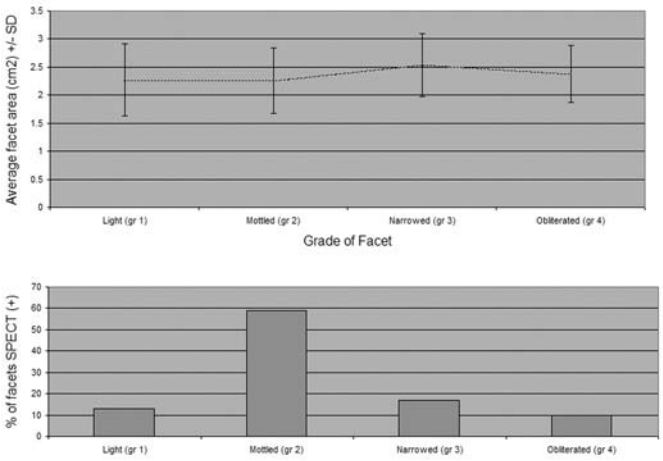

FIGURE 7. *Facet Grade, overall area, and SPECT results. The results of facet area (in cm^2) and % of facet joints that are SPECT (+) have been collected together under a single Figure. Note that in the first column,* Light*, the average facet area of a facet joint with* Light *synovium was 2.27 cm^2 ± 0.64 seconds.D. Less than 10% of facets in the Light column were "hot." Facets with* Mottled *appearance (Column 2) demonstrated the highest likelihood of being "hot" to SPECT. The group with* Narrowed *synovium (Column 3) had the largest facet area, 2.54 cm^2 ± 0.56 seconds.D. No statistically significant differences were found in facet area or SPECT results between the* Light *and* Obliterated *group. Statistically significantly increased facet area was noted in the* Narrowed *group. Highest specificity for a "hot" facet on SPECT was noted in the* Mottled *group.*

Thus, the pathophysiology of this structure is perhaps better examined in the context of the scientific literature on other synovial joints. Animal models for knee and facet degeneration have afforded us a glimpse of the progressive history of synovial joint degeneration (41). Chronic degenerative osteoarthritic processes in these structures involve active synovial inflammation, which can often be identified on SPECT scans (9, 10, 37, 58, 65, 75, 76). Thus, SPECT provides an objective, non-invasive and functional test for facet joint inflammation.

In this study, we attempted to correlate information obtained from radioisotope scans, which provide functional data, and MRI studies which provide anatomic delineation. We identified four types of synovial architecture on T2WI axial images: LightMOtled, Narrowed, and Obliterated and graded them from 1 to 4.

The Mottled group was no different in overall size or shape or osteophytic overgrowth compared to the Light group. However, the Mottled group exhibited equal to increased synovial area compared to the other groups (*Fig. 6*). The Mottled group also exhibited a high specificity for positive SPECT analysis and had odds ratio of 13.0 for a coincident "hot" facet compared to the other groups (*Fig. 7*). The presence of increased fluid presence and SPECT positivity in certain facets with a Mottled synovial appearance lends credence to the presence of the inflamed facet joint.

Interestingly, hypertrophic facets were not found to be associated with increased radiotracer uptake, even if there was an asymmetry between the left and right sides. Facet area seemed to enlarge for the Narrowed group but was within normal for the Obliterated group, suggesting perhaps that facet size tends to return to baseline once synovial obliteration or fusion has occurred (*Fig. 7*).

Our findings support the commonly inferred notion that (a) abnormally enlarged facets are not necessarily actively inflamed, (b) facet joint degeneration most likely results from adaptive protective mechanisms in response to mechanical injury and inflammation, and, (c) there exists a subtype of inflamed facet that may be treatable with injection. The four categories defined in this study likely represent a continuum of disease from normal (Light) to complete joint obliteration (Obliterated), with the Mottled and Narrowed groups being intermediary. In this paradigm, normal-appearing joints are rarely painful. An inciting event occurs wherein there is injury to the synovium and increased blood flow and joint fluid accumulation ensues. In response to mechanical stress and inflammation there is breakdown of the joint cartilage and loss of synovial fluid as represented in the Narrowed and Obliterated groups. Joint inflammation leads to localized pain characteristic of the facet syndrome. Further degeneration leads to complete loss of the joint space, loss of motion, and ankylosis, with relatively little inflammation. Osteophyte overgrowth around the joint is thus naturally protective (25, 43, 44). The protective nature of joint overgrowth may explain why, in our study, hypertrophic facets were less predictive of bone scan positivity. Overall, the sequence of facet space degeneration from Grade 1 through to 4 would parallel the natural history of the intervertebral disc and may account for the high prevalence of grossly abnormal appearing but asymptomatic facet joints.

Our study attempted to create a grading system that incorporated facet appearances on normal lumbar MRI's that could be used by physicians without specialized training. This is in contrast to previous papers that have graded facet joint appearance solely on a bony basis (47), articular cartilage findings on histopathology (19), cartilaginous abnormalities (20), facet joint space narrowing (69), or capsular abnormalities (72) as seen in *Table 3*.

Study Limitations

This study has several limitations. First, the relatively small sample size limits the universality of our findings. In particular, if facetogenic back pain exists as a heterogeneous group of joint disorders, then a larger sample size would increase our statistical power and ability to delineate these groups. In particular, the "hot" facets may represent only a subgroup of painful inflamed joints.

Second, this study only included patients with axial back pain. As such, the prevalence of "hot" facets in asymptomatic patients is unknown and has not been previously described to our knowledge in the peer-reviewed literature. Therefore, the true utility of nuclear medicine scanning such as SPECT as a screening or confirmatory tool has not been fully realized. The specificity and sensitivity of SPECT for diagnosing facetogenic

TABLE 3. Comparison of facet articular joint grading scales

Author	Key Grade Factors	Imaging Study	Grade	Grade	Grade	Grade
Kim and Wang	**Soft-tissue and bone:** articular disruption, progressive joint space narrowing, and T2WI signal intensity. A separate 'b' is used to indicate osteophytic growth	Routine MRI	Grade 1: Normal—joint space is bright in T2WI	Grade 2: articular space disruption is noted with "mottling"—overall, joint space is bright and often full of fluid. No gross joint space narrowing is evident	Grade 3: articular space is narrowed. T2WI is darker as well.	Grade 4: Articular space is obliterated.
Weshaupt et al. **(1999)**	**Bone:** facet joint space and osteophytic overgrowth	Routine MRI and CT compared	Grade 0: normal facet joint space (2–4 mm width)	Grade 1: narrowing of the facet joint space (<2mm) and/or small osteophytic and/or mild hypertrophy of the articular process	Grade 2: narrowing of the facet joint space and/or moderate osteophytes and/or moderate hypertrophy of the articular process and/or mild subarticular bone erosions	Grade 3: narrowing of the facet joint space and/or large osteophytes and/or severe hypertrophy of the articular process and/or severe subarticlar bone erosions and/or subchondral cysts
Grogan et al. (1997)	**Soft-tissue:** cartilage degeneration	Routine MRI with 1 mm fine slice thickness	Grade 1: uniformly thick cartilage covers the articular surfaces completely	Grade 2: cartilage covers the entire surface of the articular processes but with erosion of the irregular region evident	Grade 3: cartilage incompletely covers the articular surfaces, with regions of the underlying bone exposed to the joint	Grade 4: cartilage is absent except for traces on the articular surfaces
Grogan et al. (1997)	**Bone:** subchondral sclerosis	Routine MRI with 1 mm fine slice thickness	Grade 1: articular processes have a thin layer of cortical bone	Grade 2: cortical bone of the articular processes is focally thickened	Thickened cortical bone covers less than half of the articular processes	Dense cortical bone covers greater than half the articular process
Fujiwara et al. (2000)	**Bone:** osteophytic overgrowth	Routine MRI with 1 mm fine slice thickness	Grade 1: no osteophytes	Grade 2: possible or small osteophyte	Grade 3: definite moderate osteophyte	Grade 4: large osteophyte
Gries et al. (2000)	**Soft-tissue and bone:** histological analysis of fissures, calcifications and margins	Histology specimen	Grade 1: smooth articular surface, uniform lamellar bone, normal capsule and synovium	Grade 2: tangential cartilage flaking, minimal irregularity of tidemark, minor trabecular thickening, small osteophytes	Grade 3:cartilage fissures <1/2 depth, moderate chondrocyte death, marked irregularity of tidemark, moderate trabecular thickening, moderate osteophytes and capsular fibrosis	Grade 4: deep cartilaginous fissures, areas of total cartialge loss with extensive chondrocyte death, calcification >1/2 cartilage, eburnation of exposed bone, bone sclerosis, extensive osteophytes and marked capsular thickening
Pathria et al	**Bone:** osteoarthritic changes	Oblique radiography and CT	Grade 0: normal	Grade 1: narrowing of the facet joint space	Grade 2: narrowing plus sclerosis or hypertrophy	Grade 3: severe osteoarthritis with narrowing, sclerosis, and osteophytes

pain is unknown and supported only by small clinical studies such as the one by Holder, et al. (23).

Third, this study is limited by the deficiencies associated with MR imaging. Other reports have demonstrated that, even in large synovial joints like the knee, standard MRI studies can have a detection rate as low as 31% (63). Higher resolution MRI scanners, such as the 3.0 Tesla magnet, may increase the likelihood of detecting subtle articular cartilage abnormalities (54).

Finally, most clinicians utilize computed tomography (CT) to ascertain the degree of facet degeneration. CT offers the advantage of fine bony anatomic detail but fails to visualize the soft tissues and joint space. Weishaupt and colleagues felt CT was redundant in patients who receive MR imaging (69). In our opinion, MR gives the best anatomic detail of the components of the joint space such as cartilage and fluid (72).

Future Implications

Understanding the role of lumbar facet joints in the pathogenesis of spinal pain and degenerative spondylolysis is crucial. Because there are many pain generators in the lumbar spine, failure to recognize the facets as a potential cause of the symptoms can lead to inappropriate treatment strategies directed at incidental pathology. These issues will potentially increase with the advent of motion preservation strategies and bioengineering approaches to the spine (4, 6, 8, 66, 73, 74). In a European series by van Ooij, et al.of lumbar disc arthroplasty complications, 11 of 28 patients with complications had developed symptomatic and radiographically proven facet arthrosis (64). In Zeegers and colleagues' series of 50 patients, 6 patients underwent additional surgery for posterior element abnormalities (78), and it is now known that facetogenic disease is a relative contraindication for total disc arthroplasty.

While little is known of facet performance in vivo, several mechanical devices are currently in development to replace the facet joint or posterior structures (26, 48, 51, 52, 53, 56, 60). An ability to accurately and reliably diagnose facet disorders will thus be vital to ensure the success of such technologies.

CONCLUSION

A true understanding of the facet syndrome has not emerged in the seven decades since its first description, and there remains a lack of good clinical studies on the natural history, radiographic features, and treatment of facet disease. This report attempts to identify the MRI characteristics associated with definitive facet arthritis as seen on SPECT imaging. Ultimately, however, correlative studies that integrate histopathological, biomechanical, and radiographic investigations will be needed to improve our understanding of facetogenic back pain.

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COMMENTS

For much of its history, neurosurgery has been "limited" by the idea that the adult nervous system does not have the ability to repair itself. This has placed obvious constraints on the scope of therapeutic possibilities for our field. Over the course of the past few years, there has been tremendous interest in a "biological" solution to surmount these limitations, with considerable effort and financial resources devoted to "restorative neurosurgery." These efforts have taken the form of stem cell research and attempts to "engineer" cells at the molecular level. In this review, the authors remind us that perhaps a less "biological" approach may ultimately play a role in restoring function to the damaged nervous system. The field of neuroprosthetics is rapidly expanding, and its capabilities, which are intimately dependent upon computational power, will surely broaden with the increasing influence of new technological paradigms such as nanotechnology. This review is timely and of obvious relevance to neurosurgeons.

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Leuthardt et al. provide a general overview of the idea of neuroprosthetics. This new field involves the use of a brain computer interface (BCI) with which electrical impulses from the brain parenchyma are transformed into usable data to overcome, for example, an acquired or congenital neurological deficit. The idea of a paraplegic patient simply using their thoughts to control a mechanical wheelchair, or better yet, to walk with robotic leg braces, is very appealing. The possibilities for such a technology are seemingly limitless. However, in its current state, there are some issues that must be dealt with. The authors point out many of the hurdles that must be overcome. For example, implanted depth electrodes develop surrounding gliosis, which essentially renders them useless after a period of time. While research into new biomaterials may provide answers to inflammatory reactions of the brain, one must also consider plasticity reactions of the brain. BCI systems must be made to adapt as existing neural connections are used in novel ways. The authors also mention the idea of feedback. This can be accomplished by combining both input and output BCIs. This could be used, for example, to input proprioceptive information to the sensory cortex, while outputting commands to a robotic appendage from the motor cortex. Regardless of the current technological issues, this article gives neurosurgeons an introduction to a field in which we will undoubtedly see a rapid expansion of in the not too distant future.

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The idea of the expansion of brain functions and their interaction with the world outside the body is always considered in the human being history. Plato, in *The Republic*, used, for the first time, the word cybernetic to signify the interface between each man and the governance of people. In 1834, André-Marie Ampère included "cybernètique" in his classification of human knowledge.

The study of the communication and control of regulatory feedback between human and machines was born around the Second World War and the intersection between neurology and electronic network theory became a powerful vogue idea between 1948 and the 1970s. The organic life form interfaced with technological devices strongly stimulates many cultural fields, generates a great debate in the philosophy of mind, telecommunication engineering, and many cult movies performed in the past 20 years (*Terminal Man*, *Blade Runner*, *Minority Report*, *Matrix*) always considered the interface brain-machine under control of the machine.

The development of neuroprosthetics includes deep brain stimulation to improve movement disorders or psychiatric disease, but neuroprosthetics based on the BCI go beyond the imagination of the most writers. Interface with visual cortex could build up visual prosthesis, but the interaction with the retina, hippocampus, and cochlea are just a few examples of possible implants.

There is the awareness that clinical application of BCI has only started, and I am quite sure that improvement of computer technology and knowledge of brain activity will make feasible the clinical application of BCI on severely impaired patients. So far the electroencephalography-based systems represent a promising way to develop an interface to provide a better quality of life. Actually, we don't know which patient affected by acute lateral sclerosis or spinal cord injury will benefit from BCI, and, to select the ideal patient, a first attempt using scalp electroencephalography could be a promising suggestion. Another issue consists of the brain structure to be used for BCI; if the scalp electroencephalogram is one term of the system, it should be stressed that the Ì activity is not constant and rarely recorded (the 8-12 Hz activity is the · rhythm typical of the occipital region). Even when a motor response of a robotic arm is requested, the BCI does not necessarily have to be linked to a pericentral activity. For instance, a Ï activity should be used. The use of the single unit-based system is very attractive, but, unfortunately, is still theoretical and poses heavy limitations. The problems of a long-term function of such a method is real and the single unit approach should be considered after the resolution of the electrode encapsulation phenomenon. From this point of view, the placement on the cortex of strip or grids seems to be the ideal solution. The activity recorded is clear, has fewer artifacts, and its possible application should included on a demanding system to control seizures. Also, the subcutaneous placement of the cable connected to the grid and a subclavicular telemetry device allows safe and easy daily use of the BCI.

Electrocochleography seems to be very attractive, but the corticocortical evoked potential is a challenging alternative. Researchers have to realize that the high definition of the language, visual, and motor areas by this technique allows broad neuronal network detection.

The greatest advantage of the clinical application of BCI justifies accepting the risk faced from more invasive procedures. It must be remembered that, in epilepsy surgery, the preoperative evaluation by the placement of grids on the brain surface has proven to be a very low-risk methodology.

In my opinion, it must be remembered that BCI is not the only solution: the research on restorative neurosurgery focused on stem cells, gene therapy, and neurotrophic factors supporting brain structures, are reporting promising results.

In conclusion, the present report is particularly interesting because of the clinical perspective of the possibility of translating a neural input by an effect independent of any peripheral systems and the prospect to the neurosurgical audience what may be the future of behavioral science. The authors have provided us with a new perspective in the field of neurosurgery, particularly in restorative neurosurgery.

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