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RESEARCH ARTICLE

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Anatomic, Image-based Classification of Diseased Lumbar Spinal Motion-Segment-Preliminary Clinical Report

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ABSTRACT

Background: Multiple minimally invasive spine approaches and techniques have been developed in recent years. While the disease processes affecting the spinal motion-segment (SMS) have remained largely the same, surgical treatment options have changed radically and not necessarily in an organized fashion. This is inevitable given the rapid evolution of the technology. The current image-based diagnostic techniques, also evolving, have helped us appreciate the disease Patho anatomy in minute detail. A comprehensive classification method accounting for all anatomical participants in the spinal motion-segment pathology, tailored to treatment options, is necessary. Out of the many valid options, a spine surgeon should be able to choose a single surgical approach that is most appropriate for the Patho anatomy of his/her patient's disease. We feel that our classification system will help the spine surgeon make that important decision consistently, with minimal risk of leaving behind a significant lesion, or disrupting a structure which is not a participant in the disease process. Furthermore, universal acceptance of this classification system will make it easier for spine surgeons to communicate with each other and meaningfully compare the results of the various surgical approaches.

Purpose of the Study: To develop a comprehensive, treatment-orientated classification of lumbar spinal motion-segment disease.

Materials and Methods: Contributors to spinal motion-segment disease - intervertebral disc, facet joint, ligamentum flavum and mal-alignment were identified. The degrees of abnormalities in each of these entities were coded, and the codes were entered in a table from which the possible combinations of pathologic processes were generated.

Study of 57 lumbar MRI images (217 spinal motion-segments) was carried out to determine the prevalence of various combinations of the motion-segment disease.

Pre- and post-operative MRI-based spinal motion-segment classifications were performed to evaluate the clinical application of this classification system in 15 patients.

Results: This classification presents 494 possible combinations of the spinal motion-segment disease. Many of the combinations are only theoretical possibilities without clinical significance. Normal motion-segments, $D_0A_0L_0F_0$, represented 33.3% of the total motion-segments; $D_1A_0L_0F_0$ was 8.8%, representing bulging disc, normal alignment, ligamentum flavum and facet joint. $D_2A_0L_0F_2$ was 6.9% representing intra-annular disc herniation, normal alignment, mildly thickened ligamentum flavum, and hypertrophied superior articular process of the facet joint. 6.4% was $D_1A_0L_1F_3$ representing bulging disc, mildly hypertrophic ligamentum and hypertrophied facet joint. Clinical application of the classification revealed: Accurate anatomic classification; immediate post-operative classification changes which correlate with patient's symptoms; pre-operative, immediate post-operative and late post-operative classifications which correlate with patient's symptoms and accurately demonstrate post-operative remodeling of the motion-segment, especially after disc surgery, and accurate; and anatomic documentation of pre- and post op classifications of interlaminar endoscopic decompression.

Conclusion: A treatment-orientated, standardized classification of spinal motion-segment disease is necessary considering current multiple treatment options and availability of sophisticated pre-operative imaging techniques. Such a classification will allow standardization of treatment options for various combinations of the pathological processes. With the emergence of new technologies surgical options can be upgraded based on a standardized classification. This in turn will help minimize confusion for those who want to learn and facilitate growth in the minimally invasive technology. The preliminary results of clinical application of the classification showed it to be a very accurate patho-anatomic representation; immediate post-operative classification change reflected clinical improvement post-operatively; and precise representation of post-operative remodeling of the motion-segment one to two years post-operatively. The precision of this classification allows accurate communication regarding the pathology, between providers across the globe, and more accurate comparison of results of different surgical interventions.

ARTICLE HISTORY

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Introduction

The classification of a disease process requires thorough knowledge of the etiology, patho-anatomy, pathophysiology, and the knowledge of the internal and external factors which affect the process. Classification systems have improved over the years in all medical specialties, and as the understanding of the disease processes improves with the technology, so have the quality of classifications. Comprehensive classification systems elucidate, not only the aspects of a given disease, but also help craft treatment strategies.

The classification of the functional Spinal Motion-Segment (SMS) disease spectrum into three phases, as described by William Kirkaldy Willis, has enhanced the understanding and treatment of the spectrum of the disc and facet diseases [1]. Disc ruptures may occur acutely in an apparently normal disc, or in a degenerated disc. Disc ruptures have been described as protrusion, prolapse and sequestrated by Spengler [2]. Topographically the herniations may be described as central, paracentral, intraforaminal or extraforaminal. Fujiwara, et al and Weishaupt et al have used Pathria's 4-grade classification of the facet arthropathy to determine the utility of MRI as a diagnostic alternative to CT scan [3-5]. Both studies confirm that CT scan is slightly more accurate in grading facet degeneration but considering the superiority of MRI in diagnosing the soft tissue anomalies, MRI study is sufficient, for most part, for disc and facet disease classification. Thalgott et al utilized MRI, plain X-rays and provocative discography to, more thoroughly, evaluate the degenerative disc disease in the anterior spinal column, and facet degeneration in the posterior spinal column. This is mainly an effort to clearly define the facet disease in the era of disc arthroplasty [6].

These studies, however, fail to classify the combined effects all the elements of the functional spinal unit, or suggest treatment options based on such a classification. The severity of the disease process affecting each anatomical entity within the spinal motion-segment must be clearly delineated and classified to understand how the disease evolved to a given stage, to understand how the processes produce patient's symptoms, and use that information to craft treatment options to precisely address the offending pathologic entity, while incurring minimal collateral damage to normal tissues. The classification system presented here, describes the pathoanatomy of the motion-segment disease, as seen on the imaging studies – specifically the MRI, and CT scan, and attempts to tailor the surgical treatment strategies to the classification, with the aim of applying the least invasive surgical approach, while maximizing the surgical benefit for the patient, and minimizing the need for subsequent interventions. The classification also attempts to identify the pathoanatomic combinations which current minimally invasive approaches alone cannot address adequately or safely. It also explores pathologic combinations where a hybrid approach of minimally invasive and open approaches may be used to minimize surgical trauma, while offering the patient maximum surgical benefit in the safest possible fashion. With current trends in the development of the technology, such a classification offers an opportunity for standardizing treatment options for the given presentations, as well as promotes accurate comparison the effectiveness of the different available treatment options.

Materials and Methods

The disease of the spinal motion-segment is classified by identifying and grading the disease severity of each component of the spinal motion-segment (Table 1). The structural components identified are the disc, facet, spinal alignment, and the facet joints. The disc disease is graded "D_0, D_1, D_2, D_3 and D_4, with D_0 being normal and the D_4 showing a collapsed disc with posterior osteophytosis. The facet is graded F_0, F_1, F_2, F_3, and F_4. The ligament flavum is classified L_0, L_2, L_3, L_4, and the alignment is classified as A_0, A_1, A_3, and A_4.

Table 1: Grading the Disease Stages of the Spinal Alignment, Intervertebral Disc Disease, Facet Degeneration and Ligamentum Flavum (LF) Hypertrophy

A = Alignment	D = Disc	F = Facet	L = Ligamentum Flavum (LF)
A_0 = Normal A_1= Grade I spondy A_2 = Grade II spondy A_3 = Grade 3 & 4 Spondy A_4= Grade III & IV spondy with synovial cyst formation	D_0 = Normal disc D_1 = Global bulging disc D_2 = Contained herniation D_3 = Free frag herniation D_4 = Disc osteophytes (in canal) **Location of disc herniation:** a = Central herniation b = Paracentral herniation c =Intra- & extraforaminal hernation	F_0 = Normal facet F_1 = IAP hypertrophy F_2 = SAP hypertrophy F_3 = IAP & SAP hypertrophy F_4 = IAP & SAP hypertrophy & synovial cyst. Key: IAP = Inferior Articular Process SAP = Superior Articular Process	L_0 = Normal L_1= Minimal hypertrophy of LF L_2= Moderate hypertrophy of the LF L_3= Severe hypertrophy of the LF L_4 = Calciified/ossified

The four sets of the grading are placed in a matrix (Table 2). Combinations of the disease severity are computed as shown in the matrix.

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Table 2: The four Sets of the Grading are Placed in a Matrix (Table 2). Combinations of the Disease Severity are Computed as shown in the Matrix

	D_0 (normal disc)	**D_1 (global bulge)**	**D_2 (Intra-annular herniation)**	**D_3 (Extra-annular herniation)**	**D_4 (Disc osteophytes)**	
F_0 (Normal facet = normal foraminal height & AP diameter)	$D_0A_0L_0F_0$	$D_I A_0L_1F_0$	$D_2A_0L_2F_O$	$D_3A_0L_3F_0$	$D_4A_0L_4F_0$	A_0 (Normal alignment)
F_1 (IAP hypertrophy = ↓ lat recess AP diameter)	$D_0L_0A_0F_1$	$D_1L_1A_1F_1$	$D_2A_1L_2F_1$	$D_3A_1L_3F_1$	$D_4A_1L_4F_1$	A_1 (Retrolisthesis = ↓ disc height, global bulge)
F_2 (SAP hypertrophy = ↓ foraminal height & AP diameter)	$D_0A_2L_0F_2$	$D_1A_2L_1F_2$	$D_2A_2L_2F_2$	$D_3A_2L_3F_2$	$D_4A_2L_4F_2$	A_2 (Grade I listhesis = Mild to moderate central and foraminal stenosis)
F_3 (S&IAP hypertrophy = ↓ Foraminal height & foraminal/ lat recess AP diameter)	$D_0A_3L_0F_3$	$D_1A_3L_1F_3$	$D_2A_3L_2F_3$	$D_3A_3L_3F_3$	$D_4A_3L_4F_3$	A_3 (Grade II listhesis = moderate to severe central & foraminal stenosis)
F4 (S&IAP hyper + cyst =↓ foraminal, height & foraminal/lat recess ± central AP diameter)	$D_0A_4L_0F_4$	$D_1A_4L_1F_4$	$D_2A_4L_2F_4$	$D_3A_4L_3F_4$	$D_3A_4L_3F_4$	A_4 (Grade III&IV listhesis = extreme central and foraminal stenosis)
	L_0 (normal LF)	L_1 (mild LF hypertrophy)	L_2 (moderate LF hypertrophy)	L_3 (severe LF hypertrophy)	L_4 (Calcified, hypertrophied LT	

To determine the frequency of the occurrence of the combinations, analysis of MRI scan films in our database was carried out retrospectively.

Clinical application of the classification system was carried out prospectively using pre- and post-operative MRI studies, and preliminary results for six patients are presented herewith.

Results

Classification

The classification system described here identifies anatomic entities that contribute to the pathologic processes of spinal motion-segment, and these include intervertebral disc; facet joint; alignment of the motion-segment; and the ligamentum flavum:

Alignment

As shown in Figure 1, normal alignment is sub-classified as "A_0", retrolisthesis (A_1); grade1 spondylolisthesis (A_2); grade 2 spondylolisthesis (A_3); and grade 3&4 spondylolisthesis (A_4). Retrolisthesis, in the degenerative cascade signify primarily disc collapse and relatively well-maintained facet articular cartilage, causing the rostral vertebra to slide caudally and posteriorly, creating retrolisthesis. Depending on the degree of slippage degenerative spondylolisthesis may cause both spinal canal and foraminal stenosis.

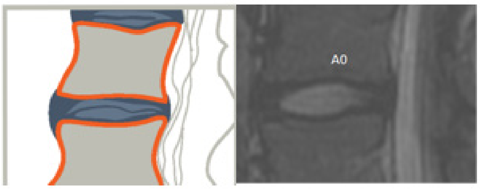

Figure 1a: Normal Alignment (A_0)

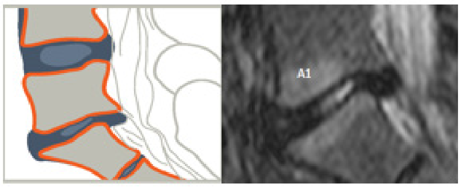

Figure 1b: Retrolisthesis (A_1)

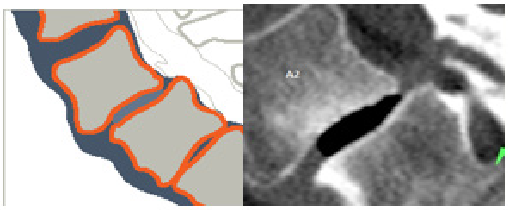

Figure 1c: Grade 1 Spondylolisthesis (A_2)

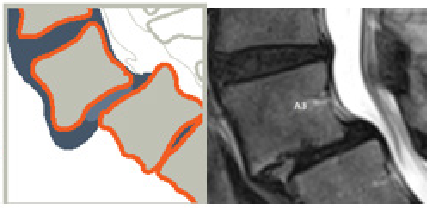

Figure 1d: Grade II Spondylolisthesis (A_3)

Figure 1e: Grade III & IV Spondylolisthesis (A_4)

Disc Disease

The normal disc is classified as "D_0". A degenerated and globally bulging disc is classified as "D_1". An intra-annular (contained) disc rupture is classified as "D_2", and an extra-annular rupture as "D_3". The degenerate disc with osteophytes encroaching on spinal and foraminal canals is classified as "D_4". The herniation may be central, paracentral and intra-/extra-foraminal herniation. In this classification, no distinction is made between an acute rupture of an apparently normal disc and a rupture of previously degenerated disc, or the topographical location of the disc lesion is made. Further classification of the disc pathology will be necessary to optimize treatment approaches.

(Figures 2a – e)

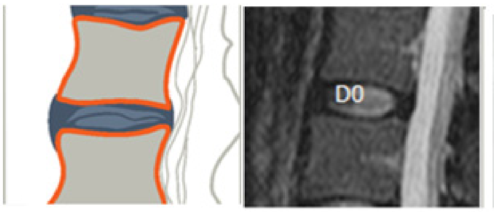

Figure 2a: Normal Disc (D_0)

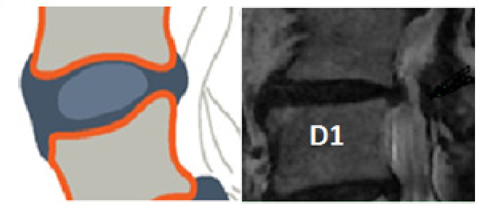

Figure 2b: Global Bulge (D_1)

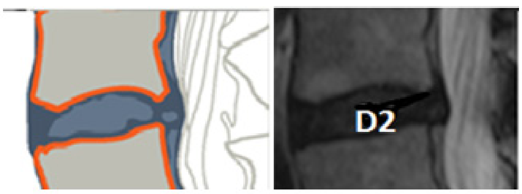

Figure 2c: Intra-Annular Disc Herniation (D_2)

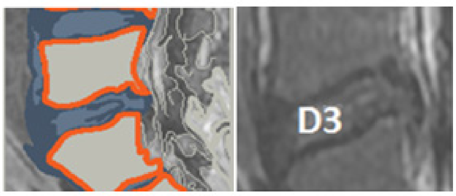

Figure 2d: Extra-Annular Disc Herniation (D_3)

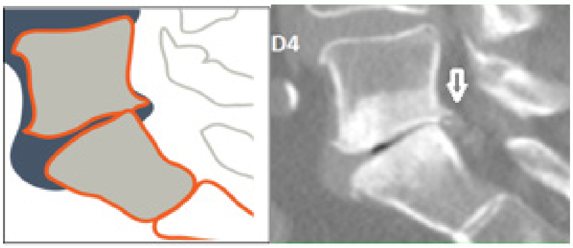

Figure 2e: Posterior Disc Osteophytes (A_4)

Facet Joint Disease

The normal facet joint is classified as "F_0". When the inferior articular process is hypertrophied, classified as "F_1", it causes encroachment on the central spinal canal along with the ligamentum flavum, and contributes to the trefoil configuration of the canal. The enlarged inferior articular process also encroaches on the lateral recess. The hypertrophied superior articular process is classified as "F_2", and when both the inferior and superior articular processes are hypertrophied (as often is the case) they are classified as "F_3" and when the pathology is associates with synovial cyst, it is classified as "F_4".

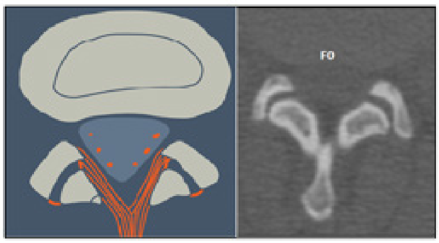

Figure 3a: Normal Facet (F_0)

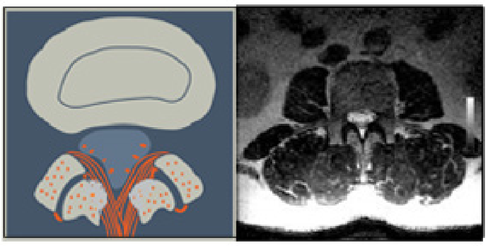

Figure 3b: Inferior Articular Process Hypertrophy (F_1)

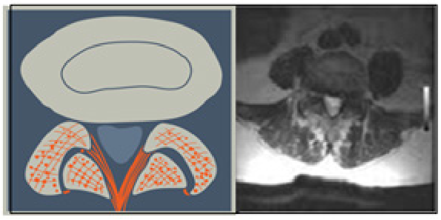

Figure 3c: Superior Articular Process Hypertrophy (F_2)

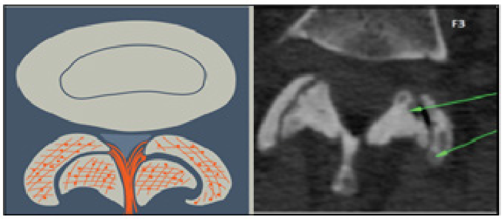

Figure 3d: Inferior and Superior Process Hypertrophy (F_3)

Figure 3e: Facet Hypertrophy and Synovial Cyst Formation (F_4)

Ligamentum Flavum

Normal ligamentum flavum is classified as "L_0". As the motion-segment loses height secondary to degeneration the interlaminar space becomes narrow and the ligamentum folds into the spinal canal and thickens. The minimal, moderate, and severe hypertrophy and in-folding of ligamentum are classified as "L_1", "L_2" and "L_3", respectively. The ligamentum is classified as "L_4", if it is calcified.

(Figure 4)

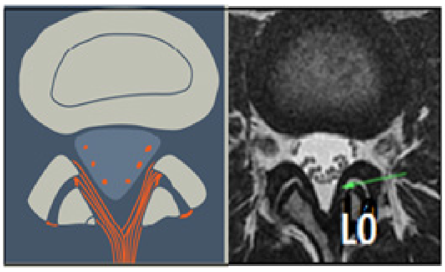

Figure 4a: Normal LF (L_0)

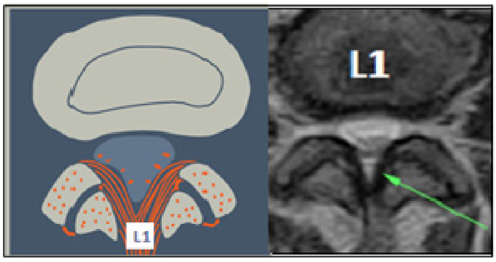

Figure 4b: Mildly Hypertrophied LF (L_1)

Figure 4c: Moderately Hypertrophied (L_2)

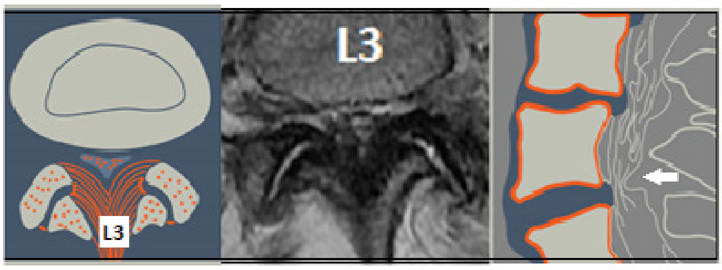

Figure 4d: Severely Hypertrophied LF (L_3)

Prevalence of Most Common Combinations of the Pathoanatomy

494 possible combinations can be computed from the matrix in Table 2. Many of these are theoretical possibilities. The retrospective study of lumbar MRI included 204 spinal motion-segments of 54 patients by the senior author showed the most prevalent combination of the motion-segment disease as shown in Table 3. Age range was 16 to 87 years (mean age 47.3 years). There were 30 male and 27 female patients. The study was undertaken to determine the frequency of the common pathologic combinations. Table 3 shows 14 of the most common combinations of the spinal motion-segment disease. As expected, the normal motion-segments, D0A0L0F0, are the most common combination (33.3%). Of the diseased combinations, D1A0L0F0, representing 8.8% of the current population is the commonest. This combination represents degenerate, globally bulging disc, without structurally obvious abnormality of the other members of the motion-segment on the magnetic resonance imaging scans. The commonest combinations in which all the four components of the motion-segments are involved represent 6% of the current population and they are D1A1L1F1, D1A2L1F3, and D1A2L1F3.

Table 3: Common Combinations of Patho-Anatomy of Spinal Motion-Segments

CODE	%	Pathologic
$D_0A_0L_0F_0$	33.3	Normal disc, normal alignment, normal ligamentum flavum, normal facet joint
$D_1A_0L_0F_0$	8.8	Degenerative global bulging disc, normal alignment, normal Ligamentum Flavum, and normal facet joint
$D_2A_0L_0F_2$	6.9	Intra-annular disc herniation, normal alignment, normal Ligamentum Flavum, and hypertrophy of superior articular process
$D_1A_0L_1F_3$	6.4	Global bulging disc, normal alignment, mild hypertrophy of ligamentum flavum, hypertrophic superior & inferior articular processes
$D_1A_0L_1F_0$	3.9	Global disc bulge, normal alignment, mild hypertrophy of LF, normal facet joint
$D_2A_0L_1F_0$	2.5	Intra-articular disc herniation, normal alignment, mild hypertrophy of Ligamentum Flavum,
$D_3A_0L_0F_0$	2.5	Extra-annular disc herniation, normal alignment, normal Ligamentum Flavum, normal facet joint
$D_1A_0L_0F_3$	2	Global disc bulge, normal alignment, normal Ligamentum Flavum, Superior and inferior articular processes
$D_1A_1L_0F_0$	2	Global disc bulge, retrolisthesis, normal Ligamentum Flavum, normal facet joint.
$D_2A_0L_0F_3$	2	Intra-discal herniation, normal alignment, normal Ligamentum Flavum, Superior and inferior articular processes
$D_2A_0L_1F_3$	2	Intra-annular herniation, normal alignment, mild Ligamentum Flavum hypertrophy, superior and inferior process hypertrophy
$D_1A_1L_1F_1$	3	Global disc bulge, retrolisthesis, mile Ligamentum Flavum hypertrophy, superior and inferior process hypertrophy
$D_1A_2L_1F_3$	3	Global disc bulge, grade I spondylolisthesis, mild Ligamentum Flavum hypertrophy, superior and inferior process hypertrophy

Results of Clinical Application of the Spinal Motion-Segment Classification

15 patients underwent prospective classifications of the target spinal motion-segment, pre- and post-operatively. Accurate, anatomic changes in the classification, which correlated with clinical outcomes were documented. Findings in 6 of the cases are presented herewith:

Case 1

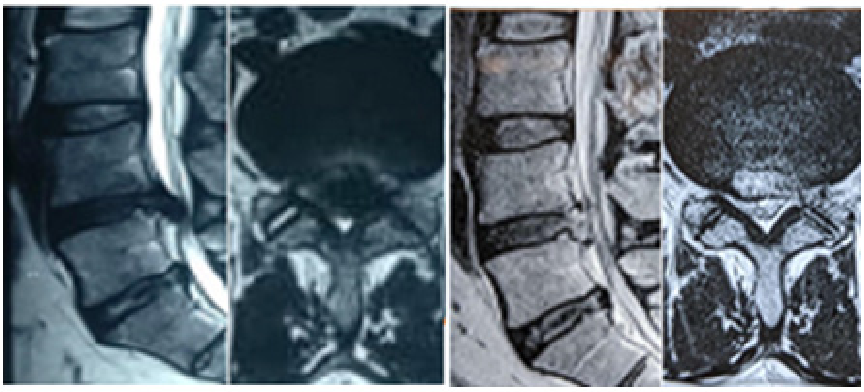

Figure 5: Pre-OP = $D_3A_0L_1F_1$ and Post-OP = $D_0A_0L_1F_2$

34-yr old male with minimal back pain, but severe left lower extremity pain and weakness. Had grade 3/5 power of left ankle dorsiflexion and plantar flexion. Strengths of Extensor Hallucis Longus and Flexor Hallucis Longus were grade 3/5. Immediate pre- and post-operative MRI classifications were - Pre-op = $D_3A_0L_1F_1$ and Post-op = $D_0A_0L_1F_2$. Patient and minimal back pain and reduced sensation in the left lower extremity. Had grade 4/5 power in the L_5 myotomes immediately post-op.

Case 2

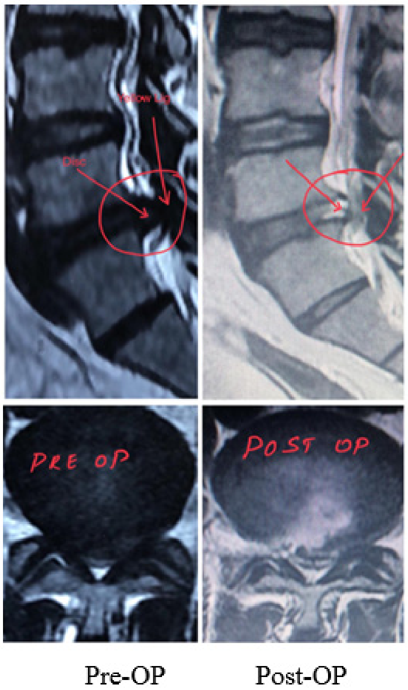

Figure 6: Pre-OP = $D_3A_0L_1F_0$ and Post-OP = $D_1A_0L_1F_0$

45-year-old male with 2 months history of severe right lower extremity pain and weakness. Patient had moderate back pain and severe lower extremity pain and weakness in the lower extremities, worse on the right side. Patient failed non-operative measures, hence had endoscopic transforaminal discectomy and foraminoplasty on the right side. Pre-operative and immediate post-operative MRI classifications were $D_3A_0L_1F_0$ and $D_1A_0L_1F_0$, respectively. Patient had immediate pain relief in his back and lower extremities. There is improvement of the motion-segment from D_3 to D_1.

Case 3

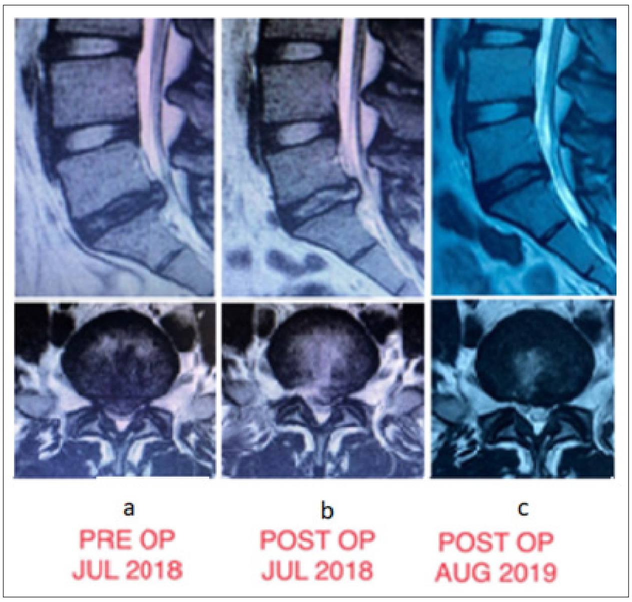

Figure 7: a. $D_1A_0L_0F_0$; b. $D_1A_0L_0F_0$; c. $D_0A_0L_0F_0$

17-years-old female with one-year history of low back pain and severe right lower extremity pain. She failed non-operative measures. She underwent transforaminal endoscopy discectomy and annuloplasty at L_5-S_1 on the right. Immediate and one-year post-operative MRI of the lumbar spine were obtained (Pre-op = $D_2A_0L_0F_0$; immediate post-op = $D_1A_0L_0F_0$; and 1-year post-op = $D_1A_0L_0F_0$). A significant remodeling of the L_5-S_1 disc is noted at one year compared with immediate post-operative image. At one-year post-operative the patient had no back or lower extremity pain.

Case 4

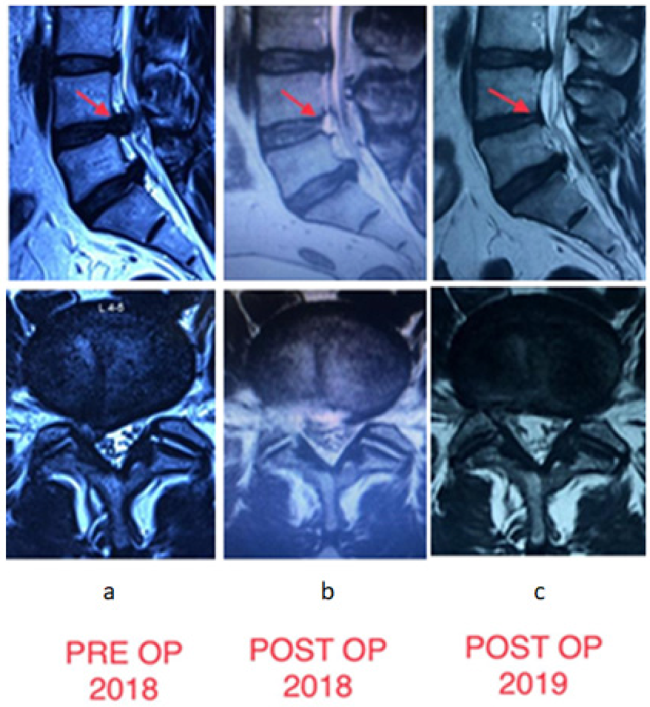

Figure 8: Pre-Operative = $D_3A_0L_0F_0$; b. Immediate Post-Operative = $D_0A_0L_0F_0$ and 1-Year Post-Operatively = $D_0A_0L_0F_0$ Post-Operatively

Case 5

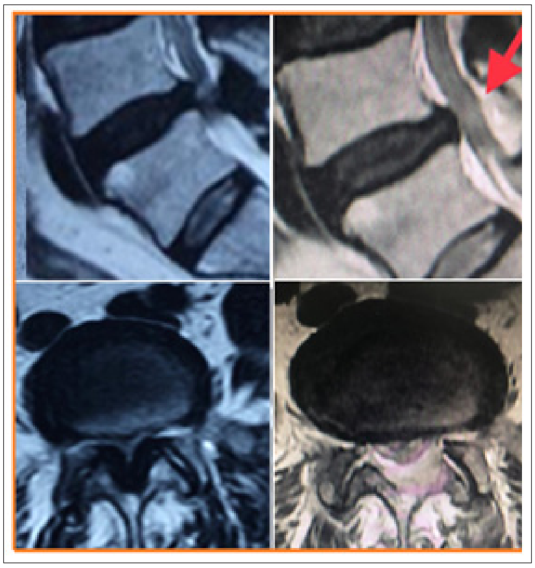

Figure 9: a. SMS classification = $D_1A_0L_3F_3$; b. SMS classification = $D_1A_0L_0F_2$

66-year-old female with long-standing history of neurogenic claudication, worse on the left side, and mild low back pain. Patient failed non-operative measures; hence, patient underwent endoscopic interlaminar decompression at L4-5 with relief of radicular in the lower extremities. The motion-segment classification changed from pre-operative $D_1A_0L_3F_3$ to post-operative $D_1A_0L_0F_2$, signifying a major anatomic change the inferior articular process and the ligamentum flavum.

Case 6

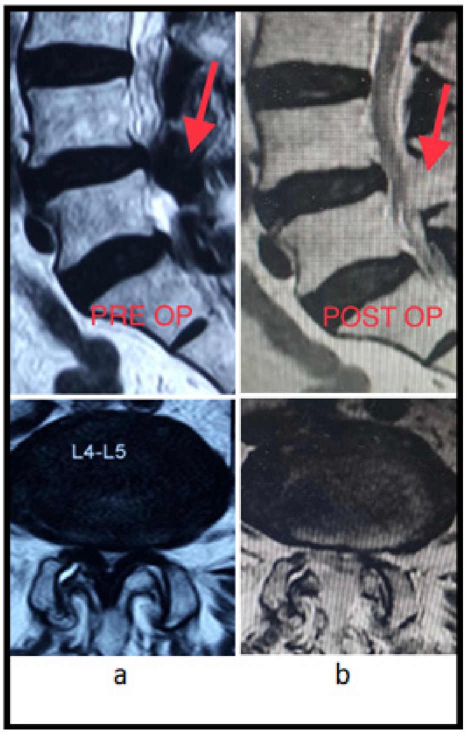

Figure 10: a. Pre-Operative Classification = $D_1A_2L_3F_3$ and b. Immediate Post-Operative Classification = $D_1A_2L_0F_2$

75-year-old female with long-standing history of neurogenic claudication and progressive weakness in the lower extremities. The patient and endoscopic interlaminar decompression. The pre- and immediate post-operative MRI-based classifications are $D_1A_2L_3F_3$ and $D_1A_2L_0F_2$, respectively.

Discussion

A treatment-orientated classification of spinal motion-segment disease is necessary considering the many emerging treatment options and the availability of sophisticated imaging technologies which reveal fine details of its pathoanatomy. Such a classification will help standardization of treatment options for the various combinations of the pathoanatomic processes. Because of lack of precise, anatomic classification of spinal motion-segment disease, it has been difficult to have meaningful comparisons of outcomes of different treatment options, and it is our hope this classification system will solve that problem.

Rather than introducing new concepts regarding structural aspects of the spinal motion-segment pathology, this classification presents all the four anatomical entities involved in the functional unit disease in a manner that expresses the degrees to which each contributes to patient's symptoms and objective findings. Based on the patho-anatomic combination and presenting clinical facts the surgeon may then select the best approach from available options. Treatment-based classification is best exemplified by the various classification of scoliosis over the last several decades [7-16]. Before the advent of the MRI and CT scan, we were able to see only limited structural details of the disease processes such as spinal stenosis on imaging studies. As the imaging studies evolved, so did the technological capabilities of treating spinal conditions. Furthermore, the evolution of endoscopic/minimally invasive approaches to treatment of diseases; technological progress which made it possible; treatment-specific economic constraints – individual and societal; and the increasing demand by the patients for the least traumatic option of treatment, make detailed classification and sub-classification of disease necessary, so that treatment may be tailored to a specific characteristic of the disease in a targeted fashion [10-16]. This classification method identifies 494 possible combinations. This is a staggering figure for a classification. Luckily, many of the combinations are only theoretical possibilities without clinical relevance. However, as shown by this study the number of clinically relevant combinations is quite large and requires computer software development for ease of use. It is important to appreciate that, while the multitude of clinically relevant pathologic combinations may appear superfluous today, with the emergence of better refined less invasive approaches these sub-classifications may become important.

Several studies have looked at the roles of the structures of spinal motion-segment in the development of spinal stenosis. Haig AJ et al, concluded although the ligamentum flavum appears to get thicker with age, other factors, including clinical diagnosis, pain, and function, do not appear to relate to the ligamentum flavum width [17]. Our study of lumbar MRI study of spinal motion-segment reveals wide variation in the absolute anteroposterior thicknesses of the ligamentum flavum in normal motion-segments, without any evidence of encroachment on the spinal canal dimensions. Conversely, an otherwise thin ligamentum flavum has been found to encroach on the spinal canal diameter. It appears hypertrophy of the inferior articular process and narrowing of the interlaminar space are – either individually or in combination, essential for the encroachment of the ligamentum flavum on the spinal canal. For the purpose of this classification, the degree of the ligamentum flavum thickening and encroachment on the spinal canal were used. Liu HX, et al, observed there is a close relationship between the severity of facet joint osteoarthritis and ligamentum flavum thickness. While defining the cortical margins of the articular processes are difficult on the MRI as compared to plain CT scan, its ability to reveal the pathology of the soft tissues including the disc, the facet capsule, synovial cyst and the ligamentum makes MRI the authors' preferred mode of study to determine the severity of spinal stenosis [18]. Drew et al, demonstrated only moderate agreement between four surgeons who studied plain CT scan of patients regarding the presence or absence of spinal stenosis [19]. The agreement was poor with regards to the assessment of the severity of stenosis. Riew et al compared the utility of CT-Myelogram alone, MRI alone, and CT-myelogram and MRI together in pre-operative planning and found the plans generated from CT-myelogram alone was like the one generated from the combined studies [20]. They concluded CT-myelogram was more useful in surgical planning than MRI alone. Myelography, however, is an invasive procedure with attendant risk of complications, and these concerns outweigh any advantages the CT-myelogam may have

Combination $D_0A_0L_0F_0$, shown in Table 3, represents 33.3% of the studied sample and are normal spinal motion-segments. $D_1A_0L_0F_0$ (8.8%) represents a degenerative global disc bulge, with the other members of the motion-segment being normal. The presenting symptoms may be axial pain, radicular symptoms or combination of both. If the patient fails to respond to comprehensive non-operative treatment, based on the symptoms complex, specific patient's attributes, and diagnostic studies such as discography and facet blocks, the patient may be offered least invasive decompression alone, or decompression and stabilization. $D_2A_0L_0F_2$ (6.9%) represents an intra-annular disc rupture and hypertrophy of the superior articular process. If the non-operative regime fails, the authors' choice is endoscopic transforaminal decompression only, if symptoms are mainly radicular. If there is significant foraminal stenosis by the hypertrophied superior articular process, foraminoplasty in addition to removal of the herniated disc is imperative. Other options for the treatment are, endoscopic interlaminar, mini-open interlaminar, and open laminotomy/laminoplasty/laminectomy approach to decompress the nerve. If acute radicular symptoms are superimposed on chronic axial pain, endoscopic transforaminal/interlaminar decompression, interbody fusion and percutaneous pedicle screw implantation or dynamic stabilization may be considered [15]. $D_1A_2L_1F_3$ (2%) representing a bulging disc, grade I spondylolisthesis, mild hypertrophy of the ligamentum flavum, and hypertrophy of the facet joint may be amenable to endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation, alternatively a hybrid approach including open decompression and percutaneous interbody fusion and pedicle screw implantation may preferred to avoid neural injury if stenosis is severe. In an elderly person with stenosis due to $D_1A_0L_0F_3$ (2%), posterior decompression and interspinous/interlaminar dynamic stabilization may be a preferred minimally invasive option [21]. Currently, the commonly used MIS options for decompression, fusion, and instrumentation include MIS-Transforaminal lumbar interbody fusion, direct lateral lumbar interbody fusion, pre-sacral interbody fusion and interlaminar fusion and instrumentation [22-28].

The results of the clinical application of the SMS classification presented in this paper lead us to make certain conclusions

- The precise anatomic classification which conveys more accurate information of the disease, thus avoiding/minimizing risk misinterpretation of the findings by different providers across the globe and different languages.
- Pre- and immediate post-operative MRI-based classifications of the SMS, precisely documents the changes in the classification and help correlate the changes with clinical status of the patient.
- Comparison of immediate and late post-operative MRI-based classification of the SMS reveals the precise remodeling of the disc and rest of SMS, information not currently available in literature.
- The precise, MRI-based classification changes of pre- and post-endoscopic interlaminar decompression accurately demonstrate the adequacy of the decompression, and help predict factors which may lead to post-operative instability.
- Use of the classification system will help gather information which will be useful in determining the best surgical approach for a given pathoanatomic configuration of SMS disease and
- Precise SMS classification system will help accurate comparisons of outcomes of the various surgical approaches by comparing like with like.

Conclusion

The classification system described here for spinal motion-segment disease is comprehensive and identifies specific abnormalities of the disc, facet, ligamentum flavum and spinal alignment. The analysis of 204 motions segments shades light on the most common pathologic processes which require surgical intervention. The classification attempts to guide treatment options for different disease combinations to help standardize surgical management of spinal motion-segment in an era of rapid technologic transition to less invasive spine surgical options. The preliminary clinical application of the classification system reveals the precise 8-character code instead of lengthy descriptions, precise documentation of pre- and post-operative state of operated SMS, change in the classification following post-operative remodeling of the SMS, and the potential for comparing the results of different surgical interventions for precisely classified pathoanatomic entities. By targeting the diseased motion-segment component precisely, the authors believe, surgical trauma will be markedly reduced; recovery from the procedure will be shortened and cost of treatment to the patient and society will be markedly reduced, and ultimately rendered more affordable.

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