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Magnetic Resonance Imaging Predictors of Surgical Outcome in Patients with Lumbar Intervertebral Disc Herniation

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Abstract

Study Design—A retrospective cohort design

Objective—To determine if baseline MRI findings including central/foraminal stenosis, Modic change, disc morphology, facet arthropathy, disc degeneration, nerve root impingement, and thecal sac compression are associated with differential surgical treatment effect.

Summary of Background Data—Intervertebral Disc Herniation (IDH) remains the most common source of lumbar radiculopathy treated either with discectomy or non-operative intervention. Although MRI remains the reliable gold standard for diagnosis, uncertainty surrounds the relationship between MRI findings and treatment outcomes.

Methods—Three-hundred-and-seven “complete” images from patients enrolled in a previous trial were de-identified and evaluated by one of 4 independent readers. Findings were compared to outcome measures including the Oswestry Disability Index. Differences in surgery and non-operative treatment outcomes were evaluated between image characteristic subgroups and TE determined by the difference in ODI scores.

Results—The cohort was comprised of 40% females with an average age of 41.5 (± 11.6), 61% of which underwent discectomy for IDH. Patients undergoing surgery with Modic type I endplate changes had worse outcomes (−26.4 versus −39.7 for none and −39.2 for type 2, $p=0.002$) and smaller treatment effect (−3.5 versus −19.3 for none and −15.7 for type 2, $p=0.003$). Those with compression $\geq 1/3$ showed the greatest improvement within the surgical group (−41.9 for $\geq 1/3$ versus −31.6 for none and −38.1 for $< 1/3$, $p=0.007$), and the highest TE (−23 compared to −11.7 for none and −15.2 for $< 1/3$, $p=0.015$). Furthermore, patients with minimal nerve root impingement demonstrated worse surgical outcomes (−26.5 versus −41.1 for “displaced” and −38.9 for “compressed”, $p=0.016$).

Conclusion—Among patients with IDH, those with thecal sac compression $\geq 1/3$ had greater surgical treatment effect than those with small disc herniations and Modic type I changes.

Additionally, patients with nerve root “compression” and “displacement” benefit more from surgery than those with minimal nerve-root impingement.

Keywords

Intervertebral Disc Herniation; Lumbar; surgical outcome; Magnetic Resonance Imaging; Modic Change; Thecal Sac Compression

Introduction

Lumbar intervertebral disc herniations (IDH) are the most common source of lumbar radiculopathy; elective discectomy provides the most immediate relief of those symptoms although many patients do well without surgery [1–5]. Magnetic Resonance Imaging (MRI) is considered the diagnostic imaging procedure of choice for IDH [6] as it can provide exquisite morphologic detail of the disc abnormality [7, 8]. Unfortunately, the relationship between findings on MRI and clinical course remains controversial, with several studies showing a high prevalence of disc “herniations” in asymptomatic subjects [9–12].

Some studies have found a relationship between larger pre-operative disc fragment size and/or small canal area with improved surgical outcomes following lumbar discectomy [13, 14]. Other studies have looked at the effect of vertebral endplate or so-called Modic changes in patients with IDH and found that patients with baseline type 1 Modic changes have worse surgical outcomes [15–17]. To date however, no studies have looked systematically at a broad range of MRI findings as potential predictors of outcome for both surgical and non-operatively treated patients with IDH.

In previous studies, we have reported on the intra and inter-rater reliability of a number of MRI parameters [18, 19]. In this study we evaluate the outcomes of subgroups determined by baseline MRI findings on the outcomes with surgery or non-operative treatment in order to identify those most likely to benefit from each treatment approach.

Methods

Patient images were collected from a previous study which combined a randomized controlled trial and an observational cohort study, including those with a diagnosis of intervertebral disc herniation (IDH), from 13 spine clinics spanning 11 states [20]). Patients included in the IDH group of this study were over 18 years old, had radicular pain for at least six weeks with a positive nerve root tension sign and or neurologic deficit, and a confirmatory cross-sectional imaging study demonstrating a herniated disc at the level and side corresponding to their symptoms. Exclusion criteria included cauda equina syndrome, progressive neurological deficit, malignancy, significant deformity, prior back surgery and other established contra-indications to elective surgery.

Patients received either a standard open discectomy with examination and decompression of the involved nerve root [21, 22] or individualized non-operative treatment including at least physical therapy, education and counseling with home exercise instruction, and non-steroidal anti-inflammatory drugs if tolerated; physicians were instructed to individualize non-operative treatment and explore a wide range of non-operative options [23]. For this sub-group analysis looking at predictors of surgical and non-operative treatment, the randomized and observational cohorts were combined into a single as-treated analysis.

Baseline MRIs were available and archived for 763 patients out of the total IDH cohort of 1244. Images were acquired from the clinical practices at each trial site; as a result, a variety of MR imaging techniques was performed. Lumbar spine MR images were acquired using

magnets operating at field strength of 1.5 Tesla with sagittal T1 weighted spin echo (TR/TE = 400-600/8-14), sagittal T2 weighted fast spin echo or turbo spin echo (TR/TE effective = 3372-5300/60-120, with (n=37) or without (n=71) fat suppression and echo train length of 10-18) and axial T2-weighted fast spin echo (TR/TE effective 2400-3500/60-120 with echo train length of 8-16) images. Images were collected either electronically and stored directly as DICOM files or as printed films and then digitized using a high-definition scanner and stored in DICOM format. All images were de-identified for patient confidentiality. Of the archived images, 307 were “complete” (defined as having both T1 and T2 sagittal series and T2 axial series at all relevant levels) and rated as “adequate for interpretation” by one of four independent readers. Details of the reading protocols and inter-and intra-rater reliability have been previously reported [18].

The features assessed included the following: disc morphology, using the published classification scheme of “normal”, “bulge”, “broad-based protrusion”, “focal protrusion”, “extrusion”, and “sequestered” (for analytic purposes this scheme was collapsed into three categories: “normal/bulge”, “protrusion”, and “extrusion/sequestered”) [24]; thecal sac compression by the disc fragment was characterized as “none”, “<1/3”, “1/3 to 2/3”, or “> 2/3” [24]; nerve root impingement characterized as “no impingement”, “touching” (contact), “displaced” (deviation), or “compressed” [25]; disc degeneration grade ranked on a 5-level ordinal scale as described by Pfirrmann et al [26]; endplate marrow abnormality according to the Modic classification in which Modic 1 refers to edema-like signal intensity, Modic 2 refers to fat-like signal intensity and Modic 3 refers to sclerosis-like signal intensity [27]; and degree of facet osteoarthritis (OA) rated on a subjective ordinal scale of normal, mild, moderate or severe based on criteria developed by group consensus, sample illustrative images and descriptions in the literature.

Statistical Analysis

The goal of this analysis was to determine which, if any, baseline imaging characteristics were associated with differential outcomes or with a greater surgical treatment effect. Baseline characteristics collected included demographic, socioeconomic, and clinical characteristics. Baseline characteristics of the patients with “complete” imaging were compared to those without complete imaging using student T-test for continuous variables and chi square analysis for dichotomous variables to assess representativeness of those with available imaging data.

The main outcome measure was the AAOS/Modems modified version of the Oswestry Disability Index (ODI) [28]. Outcome data was evaluated as a time weighted average for each measure over 4 years. The treatment effect (TE) of surgery was defined as:

$$\text{Treatment Effect} = \text{Change in ODI}_{\text{surgery}} - \text{Change in ODI}_{\text{nonoperative}}$$

Note that for the ODI a negative TE indicated that surgery was more effective than non-operative treatment. The SF-36 Bodily Pain (BP) and Physical Functioning (PF) scales, Sciatica Bothersomeness Scale, and the Back Pain Bothersomeness scale were also assessed to check for consistency of the results across different measures of outcome [29].

Differences in outcomes for surgery and for non-operative treatment were evaluated between subgroups using ANOVA and treatment effects were evaluated using a linear regression treatment-by-subgroup interaction test. Models included an adjustment for baseline outcome score, site, age, gender, baseline sciatica, satisfaction with symptoms, self-rated health trend, herniation type, herniation level, BMI, smoking status, marital status, race, work status, insurance coverage, compensation status, joint problems, migraines, and

neurologic deficits. Outcomes were finally stratified into four groups according to the two significant imaging variables.

Results

Table 1 summarizes the characteristics of the 307 subjects with independent MRI readings compared to the rest of the IDH cohort. There was no statistically significant difference in characteristics between the two groups suggesting an absence of selection bias in those with available, “complete” imaging data.

Table 2 demonstrates the frequency of each of the baseline image characteristics within the study group. Disc bulging and grade I/II disc degeneration were rare (<5%) while all other imaging findings occurred in at least 6% of the cohort.

Table 3 illustrates the 4-year area-under the curve analysis of the ODI results for each of the imaging-defined subgroups. In the surgery versus non operative group comparison of outcome scores, Modic changes and thecal sac compression were the only two significant imaging predictors of surgical TE. In the surgery group, patients with Modic Type I endplate changes had worse outcomes (−26.4 versus −39.7 for no endplate changes and −39.2 for Type 2, $p=0.002$). Outcomes were similar in the non-operative cohort for all the Modic subgroups; this resulted in a much smaller treatment effect for surgery in the Modic Type 1 sub-group (−3.5 versus −19.3 for no endplate changes and −15.7 for Type 2, $p=0.003$). Thecal sac compression also had a significant effect on outcome. Those with compression $\geq 1/3$ showed the greatest improvement for all measures within the surgical group (−31.6 for no compression, −38.1 for $<1/3$, and −41.9 for $>1/3$ $p=0.007$). In the non-operative group the outcomes were similar across the subgroups of thecal sac compression ($p=0.32$). This resulted in the highest TE for those with compression $\geq 1/3$ with TE of −23 compared to −15.2 for those with thecal sac compression of $<1/3$ and −11.7 for those with no thecal sac compression ($p=0.015$). Although lacking a significant difference in TE, IDH nerve root impingement demonstrated significantly worse surgical outcomes for the “none/touching” group (−26.5 versus −41.1 for “displaced” and −38.9 for “compressed”, $p=0.016$). Outcomes in the non-surgical group for the three nerve root classifications were similar ($p=0.26$). For the three significant TE imaging characteristics, results of all outcome measures, including SF-36 PF and BP, Sciatica Bothersomeness, and Back Pain Bothersomeness, were similar to the ODI (see Table 4). Results for the SF-36 PF and BP scales were consistent with the findings for ODI for all the tested imaging parameters (see Appendix 1).

Figure 1 shows the analysis stratified into 4 groups by those with/without Modic Type 1 changes and with/without thecal sac compression $<1/3$. This reveals that in the group with minimal thecal sac compression and Type 1 Modic changes actually did worse with surgery. The greatest treatment effect occurred in those with $\geq 1/3$ thecal sac compression, relatively independent of the presence of Modic changes.

Discussion

Our study found that Modic changes and thecal sac compression can be used as imaging predictors of lumbar discectomy success. Specifically, we demonstrated that patient with lumbar IDH without Type 1 Modic changes and those with thecal sac compression $\geq 1/3$ on MRI had larger treatment effect with surgery than without. Furthermore, we found that in a group of individuals undergoing surgery those with nerve root “compression” or “displacement” had better surgical response than those with lesser impingement.

These findings have been echoed in the literature. A recent retrospective study by Sorlie et al. investigated Modic changes in preoperative MRIs of patients who underwent lumbar

discectomy. Similar to our study, Sorlie found that patients with Modic Type 1 changes had worse outcomes on the ODI and the EQ-5D after surgery[17]. In addition, a prospective case controlled study by Chin found that persons with IDH and no Modic changes did better after surgery [15]. These consistent findings suggest that Modic Type 1 changes may denote a pathologic source of radicular pain that is distinct from the disc herniation per se and therefore may not improve following discectomy.

The amount of herniation or degree of canal compromise has also been investigated as a potential predictor of a discectomy's benefit. Previously, research has found an association between amount of canal compromise as a result of IDH and surgical outcomes. Carragee et al found that in patients with IDH undergoing discectomy a larger anteroposterior disc length into the canal as well as larger disc area to canal ratio were independent predictors of a positive outcome[14]. Our study used "thecal sac compression" as a relative term for canal compromise secondary to disk herniation, or the amount of thecal sac space a herniated disk encroaches upon. Similar to the findings of Carragee et al., the patients in our study with $\geq 1/3$ thecal sac compression had better surgical outcomes. Conversely, those with the least amount of thecal sac compression had less benefit from surgery. Moreover, in a retrospective cohort analysis by Carlisle et al. found that in a group of patients with IDH, those who elected to undergo surgery had larger herniated disc area as compared to the non-operative group [13]. Although a relationship between greater baseline radicular pain and neurologic deficit in the surgical group was not clarified, and there was no outcome analysis done, this study may also suggest that the degree of thecal sac compression may serve as an imaging criteria for discectomy.

The characterization and reliability of nerve root compression findings on MRI have been validated by previous studies [18, 25]. However, the presence of MRI confirmed nerve root compression and its relationship to surgical outcome has been investigated by few in the literature. Sasaji et al investigated post-surgical outcomes in patients with either IDH nerve root impingement or lumbar spinal canal stenosis and found that the group with nerve root impingement secondary to IDH had significantly higher surgical improvement rate than those with spinal stenosis –92% vs. 68%, although not statistically significant ($p=0.054$) [30]. The Sasaji study did not evaluate non-surgical outcomes. Although our study found greater improvement after surgery for patients with identified nerve root "compression" or "displacement" as compared to "none/touching", the difference in the treatment effect of surgery compared to non-operative treatment was not statistically significant; this lack of statistical significance may have been a result of the very small sample size in the subgroup with minimal impingement ($n = 18$). The strict inclusion criteria for the study resulted in nearly all the subjects (94%) having either nerve-root displacement or compression.

Outside of Modic changes, thecal sac compression, and nerve root impingement, no other imaging characteristics showed statistically significant differences in outcomes. This argues that these additional characteristics are not valuable in predicting TE for lumbar IDH. Furthermore, there were essentially no significant differences in outcome for any of the imaging subgroups. This may indicate that, similar to the findings of Carragee et al., the predictors of non-operative success may be related to patient factors other than the specific anatomic features of their disc herniation[14, 31].

There were several limitations to our study. Although MRI has become the gold standard for imaging lumbar disk herniations for its ability to best capture vertebral bone and soft tissue pathology [6], some variation does exist with MRI readings[18, 32]. Although no MRI finding will have 100% intra and inter reader reliability, previous studies have demonstrated "moderate" to "good" observer agreement for accurately identifying "Modic Changes," "facet arthropathy" and "nerve root compression" [13, 25, 33–35]. Furthermore, the small

sample size of some of the subgroups (Modic type 1 changes and none/touching nerve root impingement) makes our estimates for these subgroups imprecise and potentially unstable. Thus, these findings should be confirmed in larger studies specifically designed to evaluate these features.

Conclusion

This study demonstrates that Modic Type 1 changes and thecal sac compression may be predictors of surgical treatment effect for patients with lumbar IDH. Among the patients meeting the strict inclusion criteria of our trial, those with thecal sac compression $\geq 1/3$ had a significantly larger surgical treatment effect than those with smaller disc herniations. Conversely, patients with small disc herniations and Type 1 Modic changes may not benefit substantially from discectomy. Additionally, we found that patients with nerve root “compression” or “displacement” had better surgical outcomes than those with minimal nerve root “compression” or “displacement”. These MRI findings may be useful to help guide patients with lumbar IDH to the treatment of most value for them.

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Appendix

Appendix 1

Yearly average AUC based on modeled changes from baseline in outcome scale by all image characteristics

Image Variable	Outcome Scale	Category	Surgery	Non-operative	Treatment Effect**
SPS: Central Stenosis	Bodily Pain (BP)	Any	43.7 (3.4)	23.1 (3.6)	20.7 (11.6, 29.7)
		None	42.6 (1.3)	28.1 (1.6)	14.5 (10.6, 18.5)
		p-value	0.76*	0.20*	0.21**
	Physical Function (PF)	Any	44.5 (3.3)	20.4 (3.6)	24.1 (15.5, 32.7)
		None	45.3 (1.3)	27.2 (1.5)	18.1 (14.3, 21.9)
		p-value	0.82*	0.078*	0.20**
SPS: Foraminal Stenosis	Bodily Pain (BP)	Any	44.7 (2.4)	27.9 (2.7)	16.8 (10.1, 23.5)
		None	42.1 (1.4)	27 (1.7)	15.1 (10.9, 19.4)
		p-value	0.36*	0.77*	0.68**
	Physical Function (PF)	Any	47.1 (2.4)	26.1 (2.7)	21 (14.6, 27.4)
		None	44.5 (1.4)	26.2 (1.7)	18.3 (14.3, 22.4)
		p-value	0.35*	0.98*	0.47**
Disc degeneration Grade	Bodily Pain (BP)	I/II	45.4 (5)	48 (9.5)	–2.6 (–22.2, 17)
		III	43.7 (2)	26.1 (2.3)	17.6 (11.9, 23.2)
		IV	41.1 (1.7)	28 (2)	13.1 (8, 18.1)
		V	48.6 (5.4)	26.4 (5.1)	22.2 (9.1, 35.4)
		p-value	0.46*	0.16*	0.13**
	Physical Function (PF)	I/II	47 (5)	35.3 (9.1)	11.7 (–6.8, 30.3)
		III	45.1 (2)	24.7 (2.2)	20.4 (15, 25.9)
		IV	44.5 (1.7)	26.8 (2)	17.7 (12.8, 22.6)
		V	47.2 (5.3)	29.8 (5)	17.5 (5, 29.9)
		p-value	0.93*	0.56*	0.76**
Facet Arthropathy	Bodily Pain (BP)	Mild	41.7 (1.6)	28.7 (1.9)	13 (8.3, 17.7)
		Moderate/ Severe	46.1 (2.8)	25.6 (3)	20.5 (12.9, 28.1)
		Normal	42.5 (2.7)	25.1 (3.1)	17.4 (9.7, 25)
		p-value	0.40*	0.50*	0.21**
	Physical Function (PF)	Mild	45.8 (1.6)	27.9 (1.9)	17.9 (13.3, 22.5)
		Moderate/ Severe	44.7 (2.8)	21.5 (3)	23.2 (15.9, 30.5)
		Normal	44.1 (2.7)	25.6 (3.1)	18.5 (11.3, 25.6)
		p-value	0.83*	0.19*	0.46**
Modic Changes	Bodily Pain (BP)	None	44 (1.4)	26.6 (1.7)	17.4 (13.2, 21.6)
		One	31.2 (4.3)	31.1 (4.6)	0.2 (–11.1, 11.5)

Image Variable	Outcome Scale	Category	Surgery	Non-operative	Treatment Effect**
	Physical Function (PF)	Two	42.3 (3)	27.2 (3.5)	15.2 (6.7, 23.6)
		p-value	0.019*	0.66*	0.018**
		None	46.4 (1.4)	24.4 (1.7)	22 (18, 26)
		One	36.6 (4.2)	27.7 (4.5)	9 (-1.6, 19.5)
		Two	42.6 (2.9)	31.6 (3.4)	11 (2.9, 19)
		p-value	0.054*	0.16*	0.007**
Disc Morphology	Bodily Pain (BP)	Normal/Bulge/ Protrusion	43.5 (2.7)	26.6 (2.8)	17 (10, 23.9)
		Extrusion/Sequestration	42.5 (1.4)	27.5 (1.7)	15 (10.8, 19.3)
		p-value	0.74*	0.78*	0.63**
	Physical Function (PF)	Normal/Bulge/ Protrusion	47.4 (2.6)	24.7 (2.7)	22.6 (16.1, 29.2)
		Extrusion/Sequestration	44.5 (1.4)	26.7 (1.7)	17.7 (13.7, 21.8)
		p-value	0.33*	0.53*	0.20**
IDH: Root impingement	Bodily Pain (BP)	Compressed	44 (1.4)	26.6 (1.7)	17.4 (13.1, 21.6)
		Displaced	41.6 (2.9)	30.1 (3.1)	11.5 (3.5, 19.4)
		None/Touch	29 (5.6)	25.6 (5.8)	3.4 (-11, 17.8)
		p-value	0.032*	0.57*	0.10**
	Physical Function (PF)	Compressed	45.8 (1.3)	25.9 (1.6)	19.9 (15.8, 23.9)
		Displaced	45.9 (2.9)	29.2 (3)	16.7 (9.1, 24.2)
		None/Touch	30.4 (5.4)	20.1 (5.6)	10.3 (-3.1, 23.7)
		p-value	0.021*	0.32*	0.34**
IDH: Thecal sac compression (3-group)	Bodily Pain (BP)	None	32.8 (3.3)	31.3 (4.1)	1.5 (-7.8, 10.8)
		<1/3	42.2 (1.7)	27.7 (1.9)	14.6 (9.7, 19.4)
		>=1/3	47.5 (2.1)	24.4 (2.7)	23.1 (16.7, 29.4)
		p-value	<0.001*	0.36*	<0.001**
	Physical Function (PF)	None	36.5 (3.3)	29.2 (3.9)	7.3 (-1.4, 16)
		<1/3	45.1 (1.7)	27.1 (1.9)	18 (13.4, 22.6)
		>=1/3	48.4 (2.1)	22.6 (2.7)	25.8 (19.6, 32)
		p-value	0.009*	0.28*	0.002**

* p-values are based on chi-square tests of contrasts within each treatment group. Level of herniation determined by SPORT identified level of herniation.

** p-values are based on significance of TE adjusted for: baseline outcome score, site, age, gender, baseline Sciatica, satisfaction with symptoms, self-rated health trend, herniation type, herniation level, herniation location, BMI, smoking status, race, marital status, work status, insurance coverage, compensation status, joint problems, migraines, neurologic deficit.

Appendix 2

Yearly average AUC based on modeled changes from baseline in all outcome measures by significant image variables

Image Variable	Outcome Scale	Category	Surgery	Non-operative	Treatment Effect
Modic Changes	Bodily Pain (BP)	None	44 (1.4)	26.6 (1.7)	17.4 (13.2, 21.6)

Image Variable	Outcome Scale	Category	Surgery	Non-operative	Treatment Effect
		One	31.2 (4.3)	31.1 (4.6)	0.2 (-11.1, 11.5)
		Two	42.3 (3)	27.2 (3.5)	15.2 (6.7, 23.6)
		p-value	0.019	0.66	0.018
	Physical Function (PF)	None	46.4 (1.4)	24.4 (1.7)	22 (18, 26)
		One	36.6 (4.2)	27.7 (4.5)	9 (-1.6, 19.5)
		Two	42.6 (2.9)	31.6 (3.4)	11 (2.9, 19)
		p-value	0.054	0.16	0.007
	Oswestry Disability Index (ODI)	None	-39.7 (1.2)	-20.4 (1.4)	-19.3 (-22.7, -15.9)
		One	-26.4 (3.5)	-22.8 (3.8)	-3.5 (-12.3, 5.2)
		Two	-39.2 (2.5)	-23.5 (2.9)	-15.7 (-22.4, -9)
		p-value	0.002	0.58	0.003
	Sciatica Bothersomeness	None	-9.5 (0.3)	-6.6 (0.4)	-2.9 (-3.9, -1.9)
		One	-5.7 (1)	-6.8 (1.1)	1.1 (-1.6, 3.8)
		Two	-9.6 (0.7)	-8.3 (0.8)	-1.4 (-3.5, 0.7)
		p-value	0.002	0.19	0.015
	Back Pain Bothersomeness	None	-2 (0.1)	-1.2 (0.1)	-0.8 (-1, -0.5)
		One	-1 (0.3)	-1.2 (0.3)	0.2 (-0.6, 0.9)
		Two	-1.8 (0.2)	-1.7 (0.2)	-0.1 (-0.6, 0.4)
		p-value	0.001	0.12	0.006
IDH: Root impingement	Bodily Pain (BP)	Compressed	44 (1.4)	26.6 (1.7)	17.4 (13.1, 21.6)
		Displaced	41.6 (2.9)	30.1 (3.1)	11.5 (3.5, 19.4)
		None/Touch	29 (5.6)	25.6 (5.8)	3.4 (-11, 17.8)
		p-value	0.032	0.57	0.10
	Physical Function (PF)	Compressed	45.8 (1.3)	25.9 (1.6)	19.9 (15.8, 23.9)
		Displaced	45.9 (2.9)	29.2 (3)	16.7 (9.1, 24.2)
		None/Touch	30.4 (5.4)	20.1 (5.6)	10.3 (-3.1, 23.7)
		p-value	0.021	0.32	0.34
	Oswestry Disability Index (ODI)	Compressed	-38.9 (1.1)	-20.7 (1.4)	-18.2 (-21.5, -14.8)
		Displaced	-41.1 (2.4)	-25 (2.5)	-16.2 (-22.6, -9.8)
		None/Touch	-26.5 (4.5)	-18.5 (4.7)	-8 (-19.1, 3)
		p-value	0.016	0.26	0.21
	Sciatica Bothersomeness	Compressed	-9.2 (0.3)	-6.7 (0.4)	-2.5 (-3.6, -1.4)
		Displaced	-9.7 (0.7)	-7.7 (0.7)	-2.1 (-4, -0.1)
		None/Touch	-8.4 (1.4)	-6.7 (1.4)	-1.7 (-5.2, 1.8)
		p-value	0.65	0.53	0.87
	Back Pain Bothersomeness	Compressed	-1.9 (0.1)	-1.2 (0.1)	-0.7 (-1, -0.4)
		Displaced	-1.9 (0.2)	-1.3 (0.2)	-0.6 (-1.1, -0.1)
		None/Touch	-0.8 (0.4)	-1.6 (0.3)	0.9 (-0.1, 1.8)
		p-value	0.008	0.48	0.008

Image Variable	Outcome Scale	Category	Surgery	Non-operative	Treatment Effect
IDH: Thecal sac compression (3-group)	Bodily Pain (BP)	None	32.8 (3.3)	31.3 (4.1)	1.5 (−7.8, 10.8)
		<1/3	42.2 (1.7)	27.7 (1.9)	14.6 (9.7, 19.4)
		≥1/3	47.5 (2.1)	24.4 (2.7)	23.1 (16.7, 29.4)
		p-value	<0.001	0.36	<0.001
	Physical Function (PF)	None	36.5 (3.3)	29.2 (3.9)	7.3 (−1.4, 16)
		<1/3	45.1 (1.7)	27.1 (1.9)	18 (13.4, 22.6)
		≥1/3	48.4 (2.1)	22.6 (2.7)	25.8 (19.6, 32)
		p-value	0.009	0.28	0.002
	Oswestry Disability Index (ODI)	None	−31.6 (2.8)	−19.9 (3.3)	−11.7 (−19, −4.4)
		<1/3	−38.1 (1.4)	−22.9 (1.6)	−15.2 (−19.1, −11.4)
		≥1/3	−41.9 (1.7)	−19 (2.2)	−23 (−28.1, −17.8)
		p-value	0.007	0.32	0.015
	Sciatica Bothersomeness	0.None	−7.8 (0.8)	−7.3 (1)	−0.5 (−2.7, 1.7)
		<1/3	−9.2 (0.4)	−7.5 (0.5)	−1.8 (−3, −0.5)
		≥1/3	−9.8 (0.5)	−5.8 (0.7)	−4 (−5.6, −2.4)
		p-value	0.093	0.12	0.019
	Back Pain Bothersomeness	0.None	−1.5 (0.2)	−1.4 (0.3)	−0.1 (−0.7, 0.5)
		<1/3	−1.9 (0.1)	−1.3 (0.1)	−0.5 (−0.8, −0.2)
		≥1/3	−2 (0.1)	−1.1 (0.2)	−0.9 (−1.3, −0.5)
		p-value	0.063	0.48	0.066
Thecal Sac Compression/ Modic Changes	Bodily Pain (BP)	thecal=<1/3 modic=one	19.5 (7.8)	33.6 (6.1)	−14.1 (−31.7, 3.6)
		thecal=<1/3 modic=none/2	40.9 (1.6)	27.9 (1.8)	13.1 (8.6, 17.5)
		thecal=≥1/3 modic=one	37.9 (5.2)	28.4 (7)	9.5 (−6.5, 25.5)
		thecal=≥1/3 modic=none/2+	49.2 (2.3)	23.5 (2.9)	25.7 (18.7, 32.7)
		p-value	<0.001	0.41	<0.001
	Physical Function (PF)	thecal=<1/3 modic=one	21.4 (7.5)	33.2 (6.1)	−11.8 (−28, 4.4)
		thecal=<1/3 modic=none/2	43.9 (1.5)	27 (1.8)	17 (12.7, 21.2)
		thecal=≥1/3 modic=one	43.4 (5.1)	24.2 (6.8)	19.2 (4.2, 34.1)
		thecal=≥1/3 modic=none/2+	49.2 (2.3)	22 (2.9)	27.2 (20.5, 33.9)
		p-value	0.003	0.29	<0.001
	Oswestry Disability Index (ODI)	thecal=<1/3 modic=one	−7.6 (6.2)	−30.3 (5.2)	22.7 (9.4, 35.9)
		thecal=<1/3 modic=none/2	−38.3 (1.3)	−21.2 (1.5)	−17.2 (−20.7, −13.6)
		thecal=≥1/3 modic=one	−36.7 (4.4)	−13.2 (5.8)	−23.5 (−35.9, −11.1)
		thecal=≥1/3 modic=none/2+	−42.7 (2)	−19.5 (2.4)	−23.3 (−28.8, −17.7)
		p-value	<0.001	0.14	<0.001
	Sciatica Bothersomeness	thecal=<1/3 modic=one	−3.3 (1.9)	−8.8 (1.4)	5.6 (1.2, 9.9)
		thecal=<1/3 modic=none/2	−9.1 (0.4)	−7.3 (0.4)	−1.9 (−3, −0.8)
		thecal=≥1/3 modic=one	−6.8 (1.2)	−4.4 (1.6)	−2.3 (−6, 1.4)
		thecal=≥1/3 modic=none/2+	−10.3 (0.5)	−6 (0.7)	−4.3 (−6, −2.6)

Image Variable	Outcome Scale	Category	Surgery	Non-operative	Treatment Effect
		p-value	<0.001	0.092	<0.001
	Back Pain Bothersomeness	thecal=<1/3 modic=one	-0.2 (0.6)	-1.2 (0.4)	1.1 (-0.2, 2.4)
		thecal=<1/3 modic=none/2	-1.8 (0.1)	-1.4 (0.1)	-0.5 (-0.8, -0.2)
		thecal=>=1/3 modic=one	-1.3 (0.3)	-1.2 (0.4)	-0.2 (-1.2, 0.8)
		thecal=>=1/3 modic=none/2+	-2.2 (0.1)	-1.1 (0.2)	-1.1 (-1.5, -0.6)
		p-value	<0.001	0.62	0.004

P-values are based on chi-square tests of contrasts. Level of herniation determined by SPORT identified level of herniation.

**

Adjusted for: baseline outcome score, site, age, gender, baseline Sciatica, satisfaction with symptoms, self-rated health trend, herniation type, herniation level, herniation location, BMI, smoking status, race, marital status, work status, insurance coverage, compensation status, joint problems, migraines, neurologic deficit.

Key points

1. Controversy surrounds MRI readings of IDH with several studies showing a high prevalence of disc “herniations” in asymptomatic subjects
2. In this study’s cohort the absence of Modic type 1 changes, the presence of thecal sac compression $\geq 1/3$, and nerve root “compression” and “displacement” are associated with better surgical outcomes
3. These image characteristics may be used as a clinical adjunct to guide lumbar IDH interventions.

Figure 1.
Negative ODI treatment effect by thecal sac compression/Modic changes

Table 1

Baseline characteristics of IDH patients with “complete” imaging versus incomplete imaging

	“Complete” imaging selected for study		
	Yes (n=307)	No (n=937)	p-value
Mean Age (stdev)	41.5 (11.6)	41.7 (11.3)	0.76
Female	123 (40%)	399 (43%)	0.48
Ethnicity: Not Hispanic	287 (93%)	899 (96%)	0.11
Race - White	264 (86%)	808 (86%)	0.99
Education - At least some college	219 (71%)	704 (75%)	0.21
Marital Status - Married	214 (70%)	647 (69%)	0.88
Work Status			0.097
Full or part time	176 (57%)	601 (64%)	
Disabled	52 (17%)	117 (12%)	
Retired	15 (5%)	33 (4%)	
Other	64 (21%)	186 (20%)	
Compensation - Any	63 (21%)	153 (16%)	0.11
Mean Body Mass Index (BMI), (stdev)	27.5 (5.2)	28.1 (5.6)	0.087
Smoker	76 (25%)	225 (24%)	0.85
Comorbidities			
Hypertension	33 (11%)	137 (15%)	0.11
Diabetes	9 (3%)	41 (4%)	0.34
Osteoporosis	6 (2%)	14 (1%)	0.77
Heart Problem	21 (7%)	42 (4%)	0.14
Stomach Problem	29 (9%)	121 (13%)	0.13
Bowel or Intestinal Problem	18 (6%)	65 (7%)	0.60
Depression	31 (10%)	116 (12%)	0.33
Joint Problem	56 (18%)	173 (18%)	1
Other	87 (28%)	257 (27%)	0.81
Time since most recent episode > 6 months	65 (21%)	208 (22%)	0.77
Bodily Pain (BP) Score	25.5 (18.6)	26 (17.9)	0.73
Physical Functioning (PF) Score	36.3 (24.9)	38.4 (25.7)	0.23
Mental Component Summary (MCS) Score	45.5 (11.9)	45 (11.5)	0.52
Oswestry (ODI)	50.1 (22.7)	49.2 (20.9)	0.49
Stenosis Frequency Index (0–24)	15.6 (5.4)	16 (5.4)	0.36
Stenosis Bothersome Index (0–24)	15.6 (5.4)	15.5 (5.3)	0.92
Back Pain Bothersomeness	4.1 (1.8)	3.9 (1.9)	0.12
Leg Pain Bothersomeness	4.8 (1.5)	4.7 (1.5)	0.16
Satisfaction with symptoms - very dissatisfied	247 (80%)	748 (80%)	0.88
Problem getting better or worse			0.51
Getting better	48 (16%)	140 (15%)	
Staying about the same	143 (47%)	411 (44%)	
Getting worse	113 (37%)	382 (41%)	

	“Complete” imaging selected for study		
	Yes (n=307)	No (n=937)	p-value
Treatment Received *			0.61
Surgery	187 (61%)	588 (63%)	
Non-operative	120 (39%)	349 (37%)	

* Treatment received over 2 years

Table 2

Baseline image characteristics at the level of herniation, among IDH patients.

(n=307)	
SPS: Central stenosis	
None	257 (85%)
Any	46 (15%)
SPS: foraminal stenosis	
None	222 (73%)
Any	81 (27%)
Modic changes	
None	222 (74%)
One	27 (9%)
Two	53 (18%)
Facet arthropathy	
Normal	64 (21%)
Mild	173 (57%)
Moderate/Severe	66 (22%)
Disc morphology	
1.Normal/Bulge	4 (1%)
2.Protrusion	67 (22%)
3.Extrusion/Seq	232 (77%)
IDH: Root impingement by disc	
None/Touch	18 (6%)
Displaced	57 (19%)
Comp	224 (75%)
Disc degeneration grade	
I/II	13 (4%)
III	112 (37%)
IV	160 (53%)
V	18 (6%)
IDH: Thecal sac compression	
None	38 (13%)
<1/3	158 (53%)
>=1/3	103 (34%)
IDH: Thecal sac compression	
None	38 (13%)
<1/3	158 (53%)
1/3–2/3	78 (26%)
>2/3	25 (8%)
Modic changes	
None	222 (73%)
Any	81 (27%)

Table 3

Yearly average AUC based on modeled changes from baseline in Oswestry Disability Index (ODI) by image variables

Image Variable	Category	Surgery	Non-operative	Treatment Effect
SPS: Central Stenosis	Any	-38.4 (2.8)	-17.9 (3)	-20.5 (-27.6, -13.3)
	None	-38.6 (1.1)	-22.1 (1.3)	-16.4 (-19.6, -13.3)
	p-value	0.95 [*]	0.20 [*]	0.3 ^{**}
SPS: Foraminal Stenosis	Any	-40.2 (2)	-21.5 (2.3)	-18.7 (-24, -13.3)
	None	-38 (1.2)	-21.5 (1.4)	-16.5 (-20, -13.1)
	p-value	0.36 [*]	0.99 [*]	0.49 ^{**}
Disc Degeneration Grade	I/II	-40.9 (4.3)	-32.4 (7.6)	-8.5 (-23.8, 6.7)
	III	-38.7 (1.7)	-21.4 (1.9)	-17.3 (-21.8, -12.8)
	IV	-37.8 (1.4)	-21.5 (1.7)	-16.3 (-20.3, -12.2)
	V	-41.4 (4.5)	-21.2 (4.3)	-20.2 (-30.7, -9.8)
	p-value	0.79 [*]	0.56 [*]	0.64 ^{**}
Facet Arthropathy	Mild	-38.1 (1.3)	-23.5 (1.6)	-14.6 (-18.4, -10.8)
	Moderate/ Severe	-39.4 (2.3)	-19 (2.5)	-20.5 (-26.5, -14.4)
	Normal	-38.9 (2.3)	-18.8 (2.6)	-20.1 (-26.1, -14.1)
	p-value	0.87 [*]	0.14 [*]	0.13 ^{**}
Modic Change	None	-39.7 (1.2)	-20.4 (1.4)	-19.3 (-22.7, -15.9)
	One	-26.4 (3.5)	-22.8 (3.8)	-3.5 (-12.3, 5.2)
	Two	-39.2 (2.5)	-23.5 (2.9)	-15.7 (-22.4, -9)
	p-value	0.002 [*]	0.58 [*]	0.003 ^{**}
Disc Morphology	Normal/Bulge/ Protrusion	-40.4 (2.2)	-21.2 (2.3)	-19.2 (-24.7, -13.7)
	Extrusion/Sequestration	-38 (1.2)	-21.5 (1.4)	-16.5 (-19.9, -13.2)
	p-value	0.35 [*]	0.90 [*]	0.40 ^{**}
IDH Nerve Root Impingement	Compressed	-38.9 (1.1)	-20.7 (1.4)	-18.2 (-21.5, -14.8)
	Displaced	-41.1 (2.4)	-25 (2.5)	-16.2 (-22.6, -9.8)
	None/Touch	-26.5 (4.5)	-18.5 (4.7)	-8 (-19.1, 3)
	p-value	0.016 [*]	0.26 [*]	0.21 ^{**}
IDH Thecal Sac Compression	None	-31.6 (2.8)	-19.9 (3.3)	-11.7 (-19, -4.4)
	<1/3	-38.1 (1.4)	-22.9 (1.6)	-15.2 (-19.1, -11.4)
	>=1/3	-41.9 (1.7)	-19 (2.2)	-23 (-28.1, -17.8)
	p-value	0.007 [*]	0.32 [*]	0.015 ^{**}

* p-values are based on chi-square tests of contrasts within each treatment group. Level of herniation determined by SPORT identified level of herniation.

** p-values are based on significance of TE adjusted for: baseline outcome score, site, age, gender, baseline Sciatica, satisfaction with symptoms, self-rated health trend, herniation type, herniation level, herniation location, BMI, smoking status, race, marital status, work status, insurance coverage, compensation status, joint problems, migraines, neurologic deficit.

Table 4
Yearly average AUC based on modeled changes from baseline in all outcome measures by significant image variables

Image Variable	Outcome Scale	Category	Surgery	Non-operative	Treatment Effect
Modic Changes	Bodily Pain (BP)	None	44 (1.4)	26.6 (1.7)	17.4 (13.2, 21.6)
		One	31.2 (4.3)	31.1 (4.6)	0.2 (-11.1, 11.5)
		Two	42.3 (3)	27.2 (3.5)	15.2 (6.7, 23.6)
		p-value	0.019	0.66	0.018
	Physical Function (PF)	None	46.4 (1.4)	24.4 (1.7)	22 (18, 26)
		One	36.6 (4.2)	27.7 (4.5)	9 (-1.6, 19.5)
		Two	42.6 (2.9)	31.6 (3.4)	11 (2.9, 19)
		p-value	0.054	0.16	0.007
	Oswestry Disability Index (ODI)	None	-39.7 (1.2)	-20.4 (1.4)	-19.3 (-22.7, -15.9)
		One	-26.4 (3.5)	-22.8 (3.8)	-3.5 (-12.3, 5.2)
		Two	-39.2 (2.5)	-23.5 (2.9)	-15.7 (-22.4, -9)
		p-value	0.002	0.58	0.003
	Sciatica Bothersomeness	None	-9.5 (0.3)	-6.6 (0.4)	-2.9 (-3.9, -1.9)
		One	-5.7 (1)	-6.8 (1.1)	1.1 (-1.6, 3.8)
		Two	-9.6 (0.7)	-8.3 (0.8)	-1.4 (-3.5, 0.7)
		p-value	0.002	0.19	0.015
IDH: Root impingement	Back Pain Bothersomeness	None	-2 (0.1)	-1.2 (0.1)	-0.8 (-1, -0.5)
		One	-1 (0.3)	-1.2 (0.3)	0.2 (-0.6, 0.9)
		Two	-1.8 (0.2)	-1.7 (0.2)	-0.1 (-0.6, 0.4)
		p-value	0.001	0.12	0.006
	Bodily Pain (BP)	Compressed	44 (1.4)	26.6 (1.7)	17.4 (13.1, 21.6)
		Displaced	41.6 (2.9)	30.1 (3.1)	11.5 (3.5, 19.4)
		None/Touch	29 (5.6)	25.6 (5.8)	3.4 (-11, 17.8)
		p-value	0.032	0.57	0.10
	Physical Function (PF)	Compressed	45.8 (1.3)	25.9 (1.6)	19.9 (15.8, 23.9)
		Displaced	45.9 (2.9)	29.2 (3)	16.7 (9.1, 24.2)
		None/Touch	30.4 (5.4)	20.1 (5.6)	10.3 (-3.1, 23.7)

Image Variable	Outcome Scale	Category	Surgery	Non-operative	Treatment Effect
IDH: Thecal sac compression (3-group)		p-value	0.021	0.32	0.34
	Oswestry Disability Index (ODI)	Compressed	-38.9 (1.1)	-20.7 (1.4)	-18.2 (-21.5, -14.8)
		Displaced	-41.1 (2.4)	-25 (2.5)	-16.2 (-22.6, -9.8)
		None/Touch	-26.5 (4.5)	-18.5 (4.7)	-8 (-19.1, 3)
		p-value	0.016	0.26	0.21
	Sciatica Botherness	Compressed	-9.2 (0.3)	-6.7 (0.4)	-2.5 (-3.6, -1.4)
		Displaced	-9.7 (0.7)	-7.7 (0.7)	-2.1 (-4, -0.1)
		None/Touch	-8.4 (1.4)	-6.7 (1.4)	-1.7 (-5.2, 1.8)
		p-value	0.65	0.53	0.87
	Back Pain Botherness	Compressed	-1.9 (0.1)	-1.2 (0.1)	-0.7 (-1, -0.4)
		Displaced	-1.9 (0.2)	-1.3 (0.2)	-0.6 (-1.1, -0.1)
		None/Touch	-0.8 (0.4)	-1.6 (0.3)	0.9 (-0.1, 1.8)
p-value		0.008	0.48	0.008	
Bodily Pain (BP)	None	32.8 (3.3)	31.3 (4.1)	1.5 (-7.8, 10.8)	
	<1/3	42.2 (1.7)	27.7 (1.9)	14.6 (9.7, 19.4)	
	>=1/3	47.5 (2.1)	24.4 (2.7)	23.1 (16.7, 29.4)	
	p-value	<0.001	0.36	<0.001	
Physical Function (PF)	None	36.5 (3.3)	29.2 (3.9)	7.3 (-1.4, 16)	
	<1/3	45.1 (1.7)	27.1 (1.9)	18 (13.4, 22.6)	
	>=1/3	48.4 (2.1)	22.6 (2.7)	25.8 (19.6, 32)	
	p-value	0.009	0.28	0.002	
Oswestry Disability Index (ODI)	None	-31.6 (2.8)	-19.9 (3.3)	-11.7 (-19, -4.4)	
	<1/3	-38.1 (1.4)	-22.9 (1.6)	-15.2 (-19.1, -11.4)	
	>=1/3	-41.9 (1.7)	-19 (2.2)	-23 (-28.1, -17.8)	
	p-value	0.007	0.32	0.015	
Sciatica Botherness	0.None	-7.8 (0.8)	-7.3 (1)	-0.5 (-2.7, 1.7)	
	<1/3	-9.2 (0.4)	-7.5 (0.5)	-1.8 (-3, -0.5)	
	>=1/3	-9.8 (0.5)	-5.8 (0.7)	-4 (-5.6, -2.4)	
	p-value	0.093	0.12	0.019	

Image Variable	Outcome Scale	Category	Surgery	Non-operative	Treatment Effect
	Back Pain Bothersomeness	0, None	-1.5 (0.2)	-1.4 (0.3)	-0.1 (-0.7, 0.5)
		<1/3	-1.9 (0.1)	-1.3 (0.1)	-0.5 (-0.8, -0.2)
		>=1/3	-2 (0.1)	-1.1 (0.2)	-0.9 (-1.3, -0.5)
		p-value	0.063	0.48	0.066
	Bodily Pain (BP)	the cal=<1/3 modic=one	19.5 (7.8)	33.6 (6.1)	-14.1 (-31.7, 3.6)
		the cal=<1/3 modic=none/2	40.9 (1.6)	27.9 (1.8)	13.1 (8.6, 17.5)
		the cal=>=1/3 modic=one	37.9 (5.2)	28.4 (7)	9.5 (-6.5, 25.5)
		the cal=>=1/3 modic=none/2+	49.2 (2.3)	23.5 (2.9)	25.7 (18.7, 32.7)
	Physical Function (PF)	p-value	<0.001	0.41	<0.001
		the cal=<1/3 modic=one	21.4 (7.5)	33.2 (6.1)	-11.8 (-28, 4.4)
		the cal=<1/3 modic=none/2	43.9 (1.5)	27 (1.8)	17 (12.7, 21.2)
		the cal=>=1/3 modic=one	43.4 (5.1)	24.2 (6.8)	19.2 (4.2, 34.1)
	Oswestry Disability Index (ODI)	the cal=>=1/3 modic=none/2+	49.2 (2.3)	22 (2.9)	27.2 (20.5, 33.9)
		p-value	0.003	0.29	<0.001
		the cal=<1/3 modic=one	-7.6 (6.2)	-30.3 (5.2)	22.7 (9.4, 35.9)
		the cal=<1/3 modic=none/2	-38.3 (1.3)	-21.2 (1.5)	-17.2 (-20.7, -13.6)
	Sciatica Bothersomeness	the cal=>=1/3 modic=one	-36.7 (4.4)	-13.2 (5.8)	-23.5 (-35.9, -11.1)
		the cal=>=1/3 modic=none/2+	-42.7 (2)	-19.5 (2.4)	-23.3 (-28.8, -17.7)
		p-value	<0.001	0.14	<0.001
		the cal=<1/3 modic=one	-3.3 (1.9)	-8.8 (1.4)	5.6 (1.2, 9.9)
	Back Pain Bothersomeness	the cal=<1/3 modic=none/2	-9.1 (0.4)	-7.3 (0.4)	-1.9 (-3, -0.8)
		the cal=>=1/3 modic=one	-6.8 (1.2)	-4.4 (1.6)	-2.3 (-6, 1.4)
		the cal=>=1/3 modic=none/2+	-10.3 (0.5)	-6 (0.7)	-4.3 (-6, -2.6)
		p-value	<0.001	0.092	<0.001
	Thecal Sac Compression/ Modic Changes	the cal=<1/3 modic=one	-0.2 (0.6)	-1.2 (0.4)	1.1 (-0.2, 2.4)
		the cal=<1/3 modic=none/2	-1.8 (0.1)	-1.4 (0.1)	-0.5 (-0.8, -0.2)
		the cal=>=1/3 modic=one	-1.3 (0.3)	-1.2 (0.4)	-0.2 (-1.2, 0.8)
		the cal=>=1/3 modic=none/2+	-2.2 (0.1)	-1.1 (0.2)	-1.1 (-1.5, -0.6)
		p-value	<0.001	0.62	0.004

P-values are based on chi-square tests of contrasts. Level of herniation determined by SPORT identified level of herniation.

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Adjusted for: baseline outcome score, site, age, gender, baseline Sciatica, satisfaction with symptoms, self-rated health trend, herniation type, herniation level, herniation location, BMI, smoking status, race, marital status, work status, insurance coverage, compensation status, joint problems, migraines, neurologic deficit.