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Manuscripts

Location of Disc Herniation May Affect Outcomes Following Lumbar Decompression

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Objective

While prior literature have compared postoperative outcomes between surgical and non surgical options based on lumbar disc herniation location and size, postoperative outcome evaluation of decompressive surgical interventions by disc herniation location and size are sparse. The objective of the study was to evaluate the impact of different

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Conflicts of Interest Statement for Kevin Jacob

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Lumbar disc herniations (LDH) on patient reported outcomes (PROMs) following minimally invasive lumbar decompression (MIS LD).

Methods

MIS LD procedures were identified from a surgical database. PROMs, including Visual Analog Scale (VAS) back/VAS leg/Oswestry Disability Index (ODI)/ Short Form Physical Component Score (SF-12 PCS)/ Patient-Reported Outcome Measurement Information System- physical Function (PROMIS- PF)/ Patient Health Questionnaire-9 (PHQ-9), were collected preoperatively and postoperatively. Minimum clinically important difference (MCID) achievement was calculated. Patients were grouped by herniation location and size as follows: paracentral/central with a massive, extruded lumbar disc (HNP I); extraforaminal/far lateral lumbar disc herniation (HNP II). Improvements in PROMs were evaluated using a paired Student's t-test. Differences in mean scores and variations in MCID achievement rates between groups at each timepoint were evaluated using a simple logistic regression.

Results

The study cohort included 142 patients. Groups differed in age, insurance collected, and hypertension. HNP I patients demonstrated significant improvements in ODI, SF-12 PCS, PROMIS PF, and PHQ-9 through the 2-year timepoint. HNP II patients demonstrated significant improvements through 12-weeks for SF-12 PCS and PROMIS PF, and through 6-months for ODI, and only at the 6-month timepoint for PHQ-9 . Location and size of herniations demonstrated a significant effect on outcomes for VAS leg, ODI, SF-12 PCS, PROMIS PF, and PHQ-9 at intermittent timepoints, all). LDHs properties did not impact MCID achievement rates .

Conclusion

Depending on the size and location of a herniation, patients may experience varying degrees of improvement throughout their course of postoperative recovery but will ultimately arrive at a similar resolution of symptoms.

INTRODUCTION

Lumbar disc herniation (LDH) is a common source of radiculopathy, characterized by radiating pain to the lower extremities, in the presence of absence of back pain. In severe cases, the compressed nerve roots may cause impaired sensory and motor function to the innervated areas (Amin, Andrade, and Neuman 2017; Allen et al. 2009). Different locations of LDHs can vary in their presentation and possible resolution of symptoms, dependent on the nerve roots impinged and characteristics of the herniated nucleus pulposus (Amin, Andrade, and Neuman 2017). While the natural disease history for LDH is generally favorable, surgery may be an option for patients who fail conservative management and have persistent neurological dysfunction or severe pain. Minimally invasive lumbar decompression (MIS LD) has become a staple for surgical intervention of single and multilevel LDH as the procedure has demonstrated effective results in relieving symptoms of disc herniation (Khanna et al. 2021; Weinstein et al. 2006, 2008). MIS LD was developed with the intent of diminishing risk of postoperative instability by preserving spinal musculature and requiring minimal posterior element disruption. This goal is achieved via tubular-access approaches developed to allow for unilateral or bilateral lumbar decompression via a combination of laminectomy, facetectomy, and foraminotomy (Narain et al. 2017). To assess successful outcomes following spinal surgery, increasing focus has been placed on Patient Reported Outcome Measures (PROMs), which provide insight to the patient's perception of their own health status (Jenkins et al. 2020; Patel et al. 2019; Finkelstein and Schwartz 2019; McCormick, Werner, and Shimer 2013). In lumbar spine surgery, common PROMs utilized include the Visual Analog Scale (VAS) for back and leg pain, Oswestry Disability Index (ODI), 12-Item Short-Form (SF-12) Physical Component Summary (PCS), Patient Reported Outcome Measurement Information System Physical Function (PROMIS-PF), and Patient Health Questionnaire-9 (PHQ-9) (Jenkins et al. 2020; Patel et al. 2019; Finkelstein and Schwartz 2019; McCormick, Werner, and Shimer 2013). While PROMs can evaluate statistically significant change in quality of life measures this does not necessarily indicate meaningful postoperative clinical improvement. To address this shortcoming, prior studies have evaluated threshold postoperative improvement values for each PROM denoting these calculated values as a Minimum Clinical Important Difference (MCID) (Parker et al. 2012; Hung et al. 2018). Given the frequency of LD surgery for the treatment of LDH and the variable demographic affected by the pathology, there has been increasing interest in factors that may influence perioperative PROMs in this population.

Previous studies have assessed the influence of sex on clinical outcomes following MIS LD (Nolte et al. 2021), noting similar PROMs and MCID achievement between males and females. Additionally, Goh et al. reported that preoperative mental health status may not affect postoperative satisfaction following spine surgery (Goh et al. 2021). However, studies comparing the impact of disc herniation location and size on PROMs following MIS LD have not been well described in the literature. While trials have assessed the necessity for surgical and nonsurgical treatment outcomes by LDH location and size (Kim et al. 2021; Gupta et al. 2020), postoperative outcome evaluation of decompressive surgical interventions are sparse.

Continued research is necessary to determine the clinical impact of LDH location on perioperative outcomes following MIS LD. By analyzing PROMs and MCID in these outcomes, greater clinical context may be determined to assess surgical success. These findings can benefit patient counseling on expectations and likely postoperative outcomes, while providing realistic data to inform patients on surgical options. Thus, the present study aims to elucidate the relationship between LDH location and the most commonly used PROMs and their MCID following MIS LD.

METHODS

PATIENT POPULATION

The Institutional Review Board (ORA #14051301) approved all aspects of the current study and all participants provided written informed consent prior to commencement. Eligible study participants were identified via a retrospective review of a single surgeon prospective database for spinal procedures performed at a single academic medical institution. Inclusion criteria for the study consisted of patients who underwent primary, elective, single-level MIS LD procedures. Any patient who had received a multi-level LD procedure or had been operated on for infection, malignancy, or trauma was excluded from the study.

SURGICAL TECHNIQUE

Fluoroscopic imaging was used to localize the affected spinal level. A unilateral approach was undertaken via paramedian 2.0-cm skin incision. Sharp dissection was conducted to the level of the deep fascia where subsequently a series of tubular dilators were docked on to the interspace(s) of interest. The final working portal was either a 16- or 21-mm non-expandable tube. A high-speed drill performed a laminectomy with bilateral partial facetectomy and foraminotomy. The underlying ligamentum flavum was resected utilizing a 3-mm Kerrison rongeur. The exiting and traversing nerve roots were visualized and noted to have an excursion distance greater than 1 cm. In subset of patients requiring a concomitant discectomy, the traversing nerve root was medially mobilized and the underlying disk fragment was resected (Ahn et al. 2016).

DATA COLLECTION

Patients were separated into two cohorts, dependent on location of disc herniation. The HNP I cohort included paracentral/central herniation with a massive, extruded lumbar disc; the HNP II cohort consisted of extraforaminal/far lateral lumbar disc herniation. Demographic and perioperative characteristics were collected, including age, self-identified gender, body mass index (BMI), ethnicity, active smoker status, medical comorbidities (diabetic status, history of myocardial infarction, hypertension, arthritis, peripheral vascular disease, renal failure, and chronic lung disease), and insurance status. Burden of comorbidities and appropriateness for surgery were collected and evaluated with the Charlson Comorbidity Index and American Society of Anesthesiologists physical classification, respectively **(Table 1)**. Perioperative characteristics were collected in this retrospective review. These variables included operative level, duration of preoperative symptoms, mean operative time, average intraoperative blood loss, total hospital or surgery center length of stay (LOS) in hours, and postoperative complications **(Table 2)**.

PROMs were utilized to assess postoperative outcomes in the cohorts. The PROMs evaluated in this analysis included the Visual Analog Scale back and leg (VAS back/leg), Oswestry Disability Index (ODI), Short Form 12-Item Physical Composite Score (SF-12 PCS), Patient-Reported Outcomes Measurement Information System-Physical Function (PROMIS-PF), and Patient Health Questionnaire (PHQ-9). All outcome measures were collected preoperatively as a baseline score, and at postoperative time points of 6-weeks, 12-weeks, 6-months, 1-year, and 2-year following surgery **(Table 3)**. MCID was assessed for the study cohorts among PROMs to evaluate the impact of disc herniation location on rates of clinically notable improvement in outcomes **(Table 4)**.

STATISTICAL ANALYSIS

Stata 16.0 (StataCorp LP, College Station, TX) was used for data analysis. Both the demographic **(Table 1)** and perioperative characteristics data **(Table 2)** had mean and standard deviation values calculated, and significance was calculated with Chi square analysis or paired sample t-test, for categorical and continuous variables, respectively. At each temporal interval of follow-up within cohorts, mean and standard deviation values were calculated for all PROMs **(Table 3**. In addition, all PROMs were assessed for MCID at each follow-up time **(Table 4)**. Variations in rates of MCID achievement between groups were assessed using a simple logistic regression. The following prior established thresholds were used for MCID values: VAS back (2.2) (Parker et al. 2012), VAS leg (5.0) (Parker et al. 2012), ODI (8.2) (Parker et al. 2012), SF-12 PCS (2.5) (Parker et al. 2012), PROMIS-PF (3.0) (Hung et al. 2018), PHQ-9 (3.0) (Parker et al. 2012).

RESULTS

DESCRIPTIVE ANALYSIS

A total of 122 patients were included in the study cohort, 74 of whom were classified in the HNP I cohort, and 48 in the HNP II cohort. The HNP I cohort had a mean age of 40.8 years with most patients (74.3%) being male and recorded a mean BMI of 28.9 kg/m^2 **(Table 1)**. The HNP II cohort had a mean age of 49.2 years, with the majority (68.7%) of male gender, and having a mean BMI of 30.1 kg/m^2 **(Table 1)**.

Table 1. Baseline Characteristics

Characteristics	Total (n=122)	HNP I (n=74)	HNP II (n=48)	*p-value
Age (mean ± SD, years)	44.1 ± 12.5	40.8 ± 12.3	49.2 ± 11.0	**<0.001**
Body Mass Index (mean ± SD, kg/m^2)	29.4 ± 5.9	28.9 ± 6.3	30.1 ± 5.2	0.251
Gender				0.502
Female	27.9% (34)	25.7% (19)	31.3% (15)	
Male	72.1% (88)	74.3% (55)	68.7% (33)	
Ethnicity				0.662
African American	9.8% (12)	9.5% (7)	10.4% (5)	
Caucasian	72.1% (88)	74.3% (55)	68.7% (33)	
Hispanic	14.8% (18)	12.2% (9)	18.7% (9)	
Asian/Other	3.3% (4)	4.0% (3)	2.2% (1)	
Diabetic Status				0.845
Non-Diabetic	94.3% (115)	94.6% (70)	93.7% (45)	
Diabetic	5.7% (7)	5.4% (4)	6.3% (3)	
Smoking Status				0.061
Non-Smoker	89.3% (109)	85.1% (63)	95.8% (46)	
Smoker	10.7% (13)	14.9% (11)	4.2% (2)	
ASA score				0.784
≤2	93.0% (93)	93.5% (58)	92.1% (35)	
>2	7.0% (7)	6.5% (4)	7.9% (3)	
CCI Score (mean ± SD)	0.92 ± 1.2	0.8 ± 1.1	1.1 ± 1.3	0.187
Insurance				**0.040**
Medicare/Medicaid	2.5% (3)	0.0% (0)	6.3% (3)	
Workers' Compensation	32.0% (39)	28.4% (21)	37.5% (18)	
Private	65.5% (80)	71.6% (53)	56.2% (27)	
Medical Comorbidities				
Myocardial Infarction	1.6% (2)	2.7% (2)	0.0% (0)	0.251
Hypertension	19.7% (24)	12.2% (9)	31.3% (15)	**0.010**
Arthritis	5.7% (7)	5.4% (4)	6.3% (3)	0.874
Peripheral Vascular Disease	0.8% (1)	1.4% (1)	0.0% (0)	0.419
Renal Failure	0.8% (1)	1.3% (1)	0.0% (0)	0.419
Chronic Lung Disease	1.7% (2)	2.8% (2)	0.0% (0)	0.244

ASA = American Society of Anesthesiologists; CCI = Charlson Comorbidity Index; SD = standard deviation
Boldface indicates significance

Differences were demonstrated between cohorts for mean age ($p<0.001$), insurance status ($p=0.040$), and hypertension status ($p=0.010$) **(Table 1).** A significantly greater proportion of patients in the HNP II cohort had a longer preoperative course of symptoms (253.9 days versus the 166.7 days in the HNP I cohort, $p=0.046$). Other perioperative characteristics for operative duration, estimated intraoperative blood loss, length of stay, and postoperative complications yielded non significantly different results among the cohorts **(Table 2)**. The HNP I cohort demonstrated a mean operative time of 48.5 minutes, mean EBL of 28.5 mL, and length of stay of 6.4 days. Comparatively, the HNP II cohort had a mean operative time of 43.7 minutes, mean EBL of 28.4 mL, and length of stay of 9.4 days **(Table 2)**. The majority of participants underwent surgery at the L4-L5 level (45.1%). Only one patient included in this study experienced postoperative complications, consisting of urinary retention requiring hospital admission and observation.

PRIMARY OUTCOME MEASURES

Both cohorts noted significant improvement in VAS Leg through the entire 2-year follow-up intervals ($p\leqslant0.048$, all). The HNP I cohort also notably reported significantly improved PROM scores at all follow-up periods for ODI, SF-12 PCS, PROMIS PF, and PHQ-9, while noting improvement in VAS Back at 6-weeks, 12-weeks, and 6-months ($p\leqslant0.048$, all). Comparatively, the HNP II cohort demonstrated variable improvement in PROMs at 12-weeks for SF-12 PCS and PROMIS PF ($p\leqslant0.028$, all), through 6-months for ODI ($p\leqslant0.031$, all), and only at the 6-month follow-up for PHQ-9 ($p=0.026$). The following differences in mean PROMs between cohorts were demonstrated: VAS Leg at 12-weeks

Table 2. Perioperative Characteristics

Characteristics	Total (n=122)	HNP I (n=74)	HNP II (n=48)	*p-value
Operative Level				
L2-3	4.1% (5)	5.4% (4)	2.1% (1)	
L3-4	16.4% (20)	6.8% (5)	31.3% (15)	
L4-5	45.1% (55)	41.9% (31)	50.0% (24)	
L5-S1	34.4% (42)	45.9% (34)	16.7% (8)	
Duration of Symptoms (Mean ± SD; days)	201.4 ± 201.3	166.7 ± 179.	253.9 ± 223.6	**0.046**
Operative Time (Mean ± SD; min)	46.7 ± 17.6	48.5 ± 19.9	43.7 ± 12.8	0.143
Estimated Blood Loss (Mean ± SD; mL)	28.5 ± 10.7	28.5 ± 11.5	28.4 ± 9.5	0.946
Length of Stay (Mean ± SD; hours)	7.5 ± 11.1	6.4 ± 7.9	9.4 ± 14.7	0.153
Postoperative Complications				
*Urinary Retention	0.8% (1)	1.3% (1)	0.0% (0)	0.419

SD = standard deviation

* Patient had a post-void residual volume of 830cc on POD0 and underwent straight catheterization. Was able to spontaneously void by discharge on POD1

(p=0.40) and 6-months (p=0.009), ODI at 12-weeks (p=0.005) and 6-months (p=0.019), SF-12 PCS at 12-weeks (p=0.015), PROMIS-PF at 1-year (p=0.037), and PHQ-9 at 1-year (p=0.028) **(Table 3)**. Rates of MCID achievement were similar between cohorts at all follow-up intervals across the PROMs **(Table 4)**. Patients in the HNP I were most likely to achieve overall MCID in PHQ-9 (90.3%), followed by SF-12 PCS (85.4%), ODI (84.3%), VAS Back (75.4%), VAS Leg (52.1%), and PROMIS-PF (31.7%). The HNP II cohort demonstrated the highest rates of MCID achievement in PHQ-9 and ODI (83.3%), followed by VAS Back (75.8%), SF-12 PCS (75.0%), PROMIS-PF (47.4%), and VAS Leg (45.5%) **(Table 4)**. These results display that location and size of lumbar disc herniation may yield a significant effect on postoperative PROMs at intermittent time points, while conversely not impacting rates of MCID achievement for the same outcomes.

DISCUSSION

Patient reported outcome measures (PROMs) provide insight into individualized experiences of pain and disability in the preoperative and postoperative setting. In addition to being able to quantify individual patient experiences, PROMs can be used to observe an individual patient's unique experience with surgical intervention (Jacob et al. 2021; Ogura et al. 2020). This can be of utility in determining efficacy of surgical intervention and postoperative satisfaction in certain subsets of patients. The modality of surgical intervention in which we were interested in studying was minimally invasive lumbar decompression (MIS LD), often utilized to treat lumbar disc herniations (LDH) (Sunderland et al. 2021). Locations of LDHs include central/paracentral, with differing locations of herniation having an associated clinical symptom profile. LDH location may additionally have an impact on postoperative clinical outcomes as well as postoperative clinical improvement. Therefore, we aimed to observe the impact of central/paracentral herniations (HNP I) versus extraforaminal/far lateral herniations (HNP II) on postoperative PROMS. Given the frequency of LD surgery for the treatment of LDH and the variable demographic affected by the pathology, there has been increasing interest in factors that may influence postoperative PROMs in this population. Furthermore, there are few studies that have examined the impact of location and size of LDH on PROMs.

CLINICAL OUTCOMES

Our findings show that there were significant improvements in the VAS back scores in both groups up to the 6 month mark and in the VAS leg scores up to the 2 year mark. In both sets of VAS scores, the HNP II cohort had higher reported levels of pain throughout the recovery process. This suggests that the extraforaminal/far lateral herniations may have been causing patients more pain in the postoperative setting than the central/paracentral herniations. This is consistent with findings observed by a study by Lee et al. in 2016 that showed evidence that foraminal/extraforaminal disc herniation was more closely related to radiating pain than central/subarticular herniation (Lee and Lee 2016). Pain associated with the foraminal/extraforaminal herniations was due to mechanical irritation or compression of the nerve roots in a more direct fashion than central/subarticular herniation (Lee and Lee 2016). Based on those findings, the observed VAS scores can be attributed to the higher propensity of foraminal/extraforaminal herniations to cause issues with peripheral nerves. From these observations in the HNP II cohort, we may glean insight into patterns seen in the rest of the PROMs. The increase in reported pain in HNP II may have been contributing to worsened recovery reported in the PROMs discussed below.

Upon review of the resulted trends in ODI, the HNP I cohort saw significant improvements in their ODI score up to the 2 year mark. The HNP II cohort showed significant improvements only up to the 6 month mark. These findings indicate less perceived recovery of disability in patients with foraminal/extraforaminal herniations compared to

Table 3. Mean PROM scores by Herniation Location

PROM	HNP I Mean ± SD	*p-value	HNP II Mean ± SD	*p-value	†p-value
VAS Back					
Preoperative	5.7 ± 2.9 (68)	-	6.2 ± 2.8 (43)	-	0.388
6-weeks	2.4 ± 2.7 (57)	**<0.001**	3.4 ± 2.6 (32)	**<0.001**	0.108
12-weeks	2.4 ± 2.8 (29)	**<0.001**	3.5 ± 2.9 (22)	**<0.001**	0.184
6-months	2.5 ± 2.3 (22)	**<0.001**	3.8 ± 3.4 (17)	**<0.001**	0.232
1-year	2.9 ± 3.3 (18)	0.054	4.2 ± 2.5 (9)	0.104	0.166
2-years	4.3 ± 3.1 (7)	0.104	6.0 ± 2.9 (5)	0.087	0.462
VAS Leg					
Preoperative	5.7 ± 3.1 (57)	-	6.9 ± 2.6 (32)	-	0.053
6-weeks	2.5 ± 2.8 (46)	**<0.001**	3.2 ± 2.6 (21)	**<0.001**	0.277
12-weeks	1.9 ± 2.6 (25)	**<0.001**	3.7 ± 2.7 (15)	**<0.001**	**0.040**
6-months	1.7 ± 2.1 (18)	**0.001**	4.2 ± 2.8 (11)	**0.007**	**0.009**
1-year	1.7 ± 2.4 (17)	**0.019**	1.9 ± 2.3 (9)	**<0.001**	0.915
2-years	3.5 ± 2.8 (7)	**0.048**	5.1 ± 2.1 (5)	**0.003**	0.201
ODI					
Preoperative	45.2 ± 21.9 (58)	-	41.6 ± 18.9 (32)	-	0.437
6-weeks	21.4 ± 17.9 (51)	**<0.001**	28.1 ± 17.6 (25)	**<0.001**	0.131
12-weeks	17.6 ± 20.3 (29)	**<0.001**	32.3 ± 18.0 (17)	**0.031**	**0.005**
6-months	18.9 ± 23.7 (21)	**<0.001**	36.1 ± 21.6 (12)	**0.027**	**0.019**
1-year	20.0 ± 20.4 (21)	**<0.001**	28.6 ± 16.8 (12)	0.123	0.164
2-years	31.6 ± 16.3 (7)	**0.011**	39.6 ± 12.1 (5)	0.215	0.582
SF-12 PCS					
Preoperative	31.0 ± 9.0 (52)	-	29.4 ± 8.6 (25)	-	0.476
6-weeks	40.1 ± 10.4 (40)	**<0.001**	35.8 ± 8.9 (23)	**0.005**	0.109
12-weeks	45.9 ± 10.6 (22)	**<0.001**	36.4 ± 8.9 (11)	**0.028**	**0.015**
6-months	44.7 ± 12.9 (20)	**0.002**	39.6 ± 11.8 (13)	0.058	0.185
1-year	46.3 ± 12.1 (19)	**<0.001**	37.8 ± 12.5 (11)	0.206	0.093
2-years	44.5 ± 8.9 (13)	**<0.001**	42.3 ± 11.1 (7)	0.247	0.663
PROMIS PF					
Preoperative	34.9 ± 7.2 (34)	-	37.5 ± 6.5 (18)	-	0.197
6-weeks	45.2 ± 11.6 (31)	**<0.001**	42.8 ± 5.4 (12)	**0.008**	0.487
12-weeks	48.9 ± 12.4 (18)	**0.001**	40.1 ± 6.5 (8)	**0.009**	0.068
6-months	47.9 ± 10.8 (15)	**0.002**	42.4 ± 8.9 (8)	0.242	0.272
1-year	50.7 ± 12.5 (17)	**<0.001**	39.4 ± 8.5 (5)	0.894	**0.037**
2-years	46.5 ± 7.1 (7)	**0.013**	43.5 ± 6.6 (5)	0.329	0.474
PHQ-9					
Preoperative	6.3 ± 5.9 (37)	-	4.4 ± 5.1 (21)	-	0.225
6-weeks	2.6 ± 3.6 (29)	**<0.001**	2.7 ± 2.5 (15)	0.094	0.905
12-weeks	1.8 ± 3.6 (19)	**<0.001**	2.7 ± 1.6 (7)	0.322	0.063
6-months	1.9 ± 3.8 (14)	**0.001**	3.1 ± 6.0 (12)	**0.026**	0.535
1-year	2.5 ± 3.3 (14)	**0.031**	8.4 ± 7.8 (5)	0.968	**0.028**
2-years	2.5 ± 2.9 (7)	**0.047**	4.7 ± 5.6 (4)	0.885	0.563

* p-values calculated using paired t-test to evaluate improvement from preoperative timepoint
† p-values calculated using linear regression to evaluate impact of location on mean values
Boldface indicates statistical significance

central/paracentral herniations. Our findings align with the retrospective cohort study by Khan et al. in 2019, which showed that far lateral lumbar disc herniations were associated with worsened ODI scores postoperatively compared to central/paracentral herniations (Khan et al. 2019). This noted difference was attributed to the anatomy of the discs,

Table 4. MCID Achievement by Herniation Location

PROM	HNP I Mean ± SD	HNP II Mean ± SD	†p-value
VAS Back (2.2) (Parker et al. 2012)			
6-weeks	64.9% (37)	59.4% (19)	0.604
12-weeks	51.7% (15)	63.6% (14)	0.396
6-months	59.1% (13)	62.5% (10)	0.832
1-year	44.4% (8)	62.5% (5)	0.399
2-year	40.0% (2)	20.0% (1)	0.497
Overall	75.4% (43)	75.8% (25)	0.973
VAS Leg (5.0) (Parker et al. 2012)			
6-weeks	39.1% (18)	38.1% (8)	0.936
12-weeks	48.0% (12)	33.3% (5)	0.366
6-months	50.0% (9)	20.0% (2)	0.132
1-year	35.3% (6)	75.0% (3)	0.076
2-year	20.0% (1)	0.0% (0)	0.999
Overall	52.1% (25)	45.5% (10)	0.607
ODI (8.2) (Parker et al. 2012)			
6-weeks	65.9% (31)	65.0% (13)	0.940
12-weeks	76.9% (20)	46.7% (7)	0.055
6-months	78.9% (15)	70.0% (7)	0.594
1-year	77.8% (14)	62.5% (5)	0.422
2-year	80.0% (4)	20.0% (1)	0.080
Overall	84.3% (43)	83.3% (20)	0.914
SF-12 PCS (2.5) (Parker et al. 2012)			
6-weeks	70.6% (24)	52.9% (9)	0.218
12-weeks	84.2% (16)	70.0% (7)	0.376
6-months	66.7% (12)	72.7% (8)	0.732
1-year	86.7% (13)	50.0% (4)	0.060
2-year	88.9% (8)	60.0% (3)	0.214
Overall	85.4% (35)	75.0% (15)	0.332
PROMIS PF (3.0) (Hung et al. 2018)			
6-weeks	32.4% (11)	31.3% (5)	0.938
12-weeks	31.6% (6)	50.0% (5)	0.333
6-months	27.8% (5)	36.4% (4)	0.629
1-year	26.7% (4)	25.0% (2)	0.931
2-year	22.2% (2)	20.0% (1)	0.922
Overall	31.7% (13)	47.4% (9)	0.245
PHQ-9 (3.0) (Parker et al. 2012)			
6-weeks	84.6% (22)	70.0% (7)	0.336
12-weeks	73.3% (11)	83.3% (5)	0.630
6-months	81.8% (9)	50.0% (3)	0.174
1-year	84.6% (11)	25.0% (1)	0.043
2-year	100.0% (5)	66.7% (2)	0.999
Overall	90.3% (28)	83.3% (10)	0.534

† p-values calculated using logistic regression to evaluate impact of location on rates of MCID achievement
Boldface indicates statistical significance

whereby lateral herniations would be more likely to compress the dorsal root ganglion compared to central ones (Khan et al. 2019). The findings are also consistent with our observations in VAS scores. The increase in pain associated with foraminal/extraforaminal herniation could cause these patients to subsequently feel more disabled in the postoperative period. However, both HNP I and HNP II cohorts eventually do show improvement from pre-operative baseline ODI (albeit moreso with HNP I). These trends are supported elsewhere in the literature as well. In one study by Kulkarni et al. that analyzed ODI trends for a mean of 22 months after micro endoscopic lumbar discectomy, mean ODI scores went from 59.5 to 22.6 (Kulkarni, Bassi, and Dhruv 2014). Therefore, our findings are consistent with known trends in ODI scores. Based on these trends, overall perception of disability is eventually expected to improve regardless of location of herniation.

In terms of physical function, our results demonstrated higher mean SF-12 PCS and PROMIS PF scores at all postoperative stages in the HNP I cohort. These findings strengthen our earlier observations that central/paracentral herniations are associated with decreased back and leg pain, decreased disability, and improved physical and mental function per SF-12 PCS and PROMIS PF. Of note, these two PROMs also were shown to improve more in the HNP I cohort. A study by Patel et al. in 2019 corroborates these observations. In this study, patients with worsened disability as rated on the PROMIS PF were shown to experience increased pain and have less improvement in ODI, SF-12 PCS, and VAS back/leg pain after MIS TLIF (Patel, Bawa, Haws, et al. 2019). Our findings match those observed by that study. Based on these similarities, it seems as if worsened pain and increased perceived disability were detriments to the overall recovery of patients after MIS LD. Upon review of our findings thus far, differences between the HNP I and HNP II cohort may have been caused by anatomic differences in location of herniation (Khan et al. 2019). These anatomic differences tend to cause more pain, which lowers a patient's ability to function and recover.

The trends in PHQ-9 data between both cohorts mirror trends observed in other PROMs. The HNP I cohort showed statistically significant improvements in PHQ-9 scores up to the 2 year mark. On the other hand, the HNP II cohort only showed significant improvement at the 6 month mark. In a retrospective cohort study in 2019 by Patel et al., preoperative depressive symptoms via PHQ-9 scores before minimally invasive transforaminal lumbar fusions were observed to be associated with less improvement in ODI and VAS scores (Patel et al. 2019). While there is little significant PHQ-9 data in the HNP II cohort, we can make some observations based on the earlier data we have gathered. The worsened VAS scores and decreased perceived functional status in the HNP II cohort may have relation to the worse improvement in PHQ-9 scores. In a literature review by Ghoneim et al., the data reviewed showed depression in patients undergoing surgery may be associated with greater postoperative pain and poor quality of life as related to health (Ghoneim and O'Hara 2016). From this data, it is likely that pain, depression, functional status, and disability all play a role in individual patient experiences in the postoperative setting. This suggests that there may be a multifactorial interplay that is contributing to the differences seen in the postoperative course between the HNP I and HNP II cohort.

In all PROMs, the HNP I cohort generally experienced more favorable results throughout their recovery. Despite the speculations that can be made throughout different time periods in the postoperative setting, the properties of the LDHs did not impact rates of MCID achievement for any PROMs. This suggests that patients with differing LDH characteristics can have different degrees of improvement in their recovery, but ultimately, they will arrive at a similar degrees of resolution. As location of disc herniation clearly differentially impacts patient postoperative improvement rates for disability, pain, physical function, and mental health surgeons can utilize results of this study to help set patient expectation preoperatively and manage patient expectations postoperatively in patients undergoing MIS LD based on location of their disc herniation.

LIMITATIONS

There are several limitations to consider when reviewing this study. First, all of the data was compiled from one spine surgeon's practice at his single academic institution. Due to all of the studied patients being selected from this one practice, generalizability to the broad population may be restricted. Statistically significant differences were noted between cohorts, specifically in mean age, insurance type, and hypertension status. A mean age of 8.4 years older in the HNP II cohort could have confounding effects on postoperative recovery and disability status. Differences in insurance types may point to social determinants of health altering postoperative outcomes and additionally may serve as source of selection bias. A 19.1% difference in the number of patients with hypertension between cohorts also complicates interpretation of recovery in the setting of overall cardiovascular health. As these three variables are potential confounders to our study's results and a notable limitation, they potentially complicate interpretation of study results. However, it was our determination that the decrease in power resulting from propensity score matching cohorts outweighed the benefit of matching. Finally, the mean duration of symptoms in the HNP II cohort was 87.2 days longer than in the HNP I cohort. Experiencing adverse symptoms for a longer period of time can confound a patient's perception of pain, functional status, disability, and mood.

CONCLUSION

Patients demonstrated significant differences in leg pain, disability, physical function, and mental health based on the properties of the herniation. However, this effect was not observed with achievement of MCID. This suggests that depending on the size and location of a herniation, patients may experience varying degrees of improvement throughout their course of postoperative recovery but will ultimately arrive at a similar resolution of symptoms.

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