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Paravertebral spinal injection for the treatment of patients with degenerative facet osteoarthropathy: Evidence of motor performance improvements based on objective assessments

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ABSTRACT

Background: This study examined short- and long-term improvements in motor performance, quantified using wearable sensors, in response to facet spine injection in degenerative facet osteoarthropathy patients.
Methods: Adults with confirmed degenerative facet osteoarthropathy were recruited and were treated with medial or intermediate branch block injection. Self-report pain, health condition, and disability (Oswestry), as well as objective motor performance measures (gait, balance, and timed-up-and-go) were obtained in five sessions: pre-surgery (baseline), immediately after the injection, one-month, three-month, and 12-month follow-ups. Baseline motor performance parameters were compared with 10 healthy controls.
Findings: Thirty patients (age = 50 (14) years) and 10 controls (age = 46 (15) years) were recruited. All motor performance parameters were significantly different between groups. Results showed that average pain and Oswestry scores improved by 51% and 24%, respectively among patients, only one month after injection. Similarly, improvement in motor performance was most noticeable in one-month post-injection measurements; most improvements were observed in gait speed (14% normal walking, $P < 0.02$), hip sway within balance tests (63% eyes-open $P < 0.01$), and turning velocity within the timed-up-and-go test (28%, $P < 0.02$). Better baseline motor performance led to better outcomes in terms of pain relief; baseline turning velocity was 18% faster among the responsive compared to the non-responsive patients.
Interpretations: Spinal injection can temporarily (one to three months) improve motor performance in degenerative facet osteoarthropathy patients. Successful pain relief in response to treatment is independent of demographic characteristics and initial pain but dependent on baseline motor performance. Immediate self-reported pain relief is unrelated to magnitude of gradual improvement in motor performance.

1. Introduction

Low back pain (LBP) is the second most common cause of disability in the United States, 80% of individuals suffer LBP during their lifetimes, and is responsible for over seven billion dollars of lost productive work time per year in the middle-aged population alone (Control and Prevention, 2001; Ricci et al., 2006; Toosizadeh et al., 2012). Treatments for LBP are costly, with an annual amount that is estimated to be $100–$200 billion (Katz, 2006). One reason for LBP is degenerative facet osteoarthropathy (DFO), a clinical and pathological construct that involves the functional failure and inflammation of the synovial facet joints resulting in chemical or mechanical stimulation of the facets with consequent, chronic pain in the lower back (Gellhorn et al., 2013; Lakemeier et al., 2013). DFO is a very common entity; among community-dwelling adults, moderate or severe lumbar DFO on CT imaging is present in an estimated 36% of adults age 45 years and younger, 67% of adults age 45–64 years, and 89% of those age 65 years and older (Suri et al., 2011).

One common method for treating chronic pain caused by DFO is steroid injection into the facet joint(s). Various techniques including intraarticular injections, medial branch blocks, and radiofrequency denervation of lumbar facet joint have been used and both the short-

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and long-term efficacies in pain relief have been explored (Bartynski et al., 2013; Furman et al., 2010; Kader et al., 2012; Lakemeier et al., 2013; Lee et al., 2010; Manchikanti et al., 2008; Toosizadeh et al., 2015). Overall, studies of spinal injections reported a success rate of LBP remittance from 10% to 63% depending upon the type of injection materials and procedures (Carette et al., 1991). Furthermore, studies have shown a sustained improvement from three to 12 months after spinal facet joint injections (Carette et al., 1991; Leung et al., 2015; Manchikanti et al., 2015).

Although several studies have been conducted to evaluate the efficacy of spinal injection in DFO patients, none of them, to the best of our knowledge, has used objective sensor-based motor performance assessments. Within these studies, the severity of LBP was commonly assessed according to the degree of subjective pain, disability, and physical impairment, using questionnaires such as visual analog pain scales, Roland-Morris, Health Survey, and Oswestry. One potential problem with these patient-reported outcome measures (PROMs) is that they incorporate psychological factors, which along with patient attitudes and beliefs, might bias outcome evaluations (McGregor et al., 1998). Objective methods of motor performance assessments, may improve diagnoses and surgical efficacy evaluations (Beurskens et al., 1995), especially when used to assess improvements in motor performance longitudinally following spinal treatment procedures (Toosizadeh et al., 2015c; Yen et al., 2016). Therefore, the purpose of the current study was to assess short- and long-term improvements in motor performance following facet spine injection in DFO patients. Sensor-based gait, balance, and timed-up-and-go (TUG) motor performance was measured, investigating three questions: 1) How long are motor performance improvements sustained after treatment? 2) What percentage of DFO patients benefit from the treatment, and what are the baseline differences in motor performance between those who benefit and those who receive no pain relief from the treatment? and 3) What are the correlations between the level of subjective pain score and motor performance measures? We hypothesized that pain relief from spinal injection would positively influence gait, balance, and TUG performance; however, we believed the effect would be short-term (less than one year) according to previous research based on subjective pain evaluations (Carette et al., 1991; Manchikanti et al., 2008). Furthermore, since previous research showed a negative association between pain severity and success rate of spinal injection (Ashraf et al., 2015; Marks et al., 1992), we expected to see that DFO patients with less pain and better baseline motor performance would benefit more from spinal injection than would those with more pain and poorer baseline motor performance. Lastly, we explored the feasibility of performing in-clinic motor performance measurements using wearable sensor technology, noting the time burden for measurements, as well as identifying tests that are more representative of motor impairments in DFO patients.

2. Methods

2.1. Participants

DFO patients, with acute pain in low back region were consecutively approached for participation from Banner University of Arizona Health Orthopedic Clinic from January 2014 to September 2015, after DFO diagnosis using plain film radiography, and confirmation using CT and MRI images. Eligibility included: older than 18 years, history of LBP symptoms for longer than one month so as to minimize the chance of spontaneous recovery, and ability to walk 20 m without assistance. Exclusion criteria included: previous spine, hip, or lower-extremity surgeries within one month prior to spinal injection, or opioid usage, as well as severe comorbidities that could affect gait- and balance-centered motor performance, including Parkinson's disease, stroke, diabetic neuropathy, or diagnosed peripheral vascular disease. A sample of healthy, who were frequency matched on age, with no self-reported history of LBP (including DFO), current or recent injuries, acute illnesses, musculoskeletal disorders, or other health-related disabilities was recruited in order to compare motor performance measures within a normal range. The study was approved by the University of Arizona Institutional Review Board. Written informed consent according to the principles expressed in the Declaration of Helsinki (Association, 2013) was obtained from all subjects before participation.

2.2. Paravertebral facet injection

DFO participants were treated with 1 cm^3 of Isovue 300, 3.5 cm^3 of 1% lidocaine plain, 3.5 cm^3 of 0.25% Marcaine plain, and 2 cm^3 of 40 mg per cm^3 of Triamcinolone combined in a 10 cm^3 syringe. All injections were done in the operating room with spinal needles and by the same orthopedic surgeon (MD). Patient were placed prone on the radiolucent table under fluoroscopic guidance and were injected after skin preparation with chloraprep. The spinal needle was inserted and advanced to the center of the pedicle cephalad border for a medial or intermediate branch block, and the pericapsular or intracapsular areas were then injected following the recommendations of the North American Spine Society (Laxmaiah Manchikanti and Boswell, 2009). After injection, patients' lower backs were cleaned again with chloraprep, Band-Aids were placed on the points of entry, and patients were asked to ambulate immediately following the injection.

2.3. PROMs

Patient-reported pain, health condition, and disability were obtained in five sessions: pre-surgery within three days prior to injection (baseline), immediately after the injection, and one month, three month, and one year follow-ups after the injection. The 10-point visual analog scale (VAS) (Langley and Sheppeard, 1985) was used to assess pain at the moment of measurement and average pain within two weeks prior to measurement. The Oswestry questionnaire (Fairbank and Pynsent, 2000) was used to evaluate LBP functional disability. In addition, subjective measures of SF-12 health survey (Ware et al., 1996) and short Falls Efficacy Scale-International (Short FES-I) (Kempen et al., 2008) were performed. Since the Oswestry, SF-12, and Short-FES-I inquire about assessments for the prior two-week period, only VAS pain was collected at the immediate session following the injection. Except for the Oswestry questionnaire not being filled out by healthy samples, all PROMs were collected from all participants.

2.4. Objective motor performance measurements

To assess changes in motor performance after spinal injection, participants performed gait, postural balance, and TUG tests at baseline, and then immediately after, one month, three month, and one year after the treatment. For all measurements, participants were asked to wear five inertial sensors (LEGSys™, Biosensics LLC, Cambridge, MA, USA). Sensors were attached to each shin, thigh, and lower back using elastic straps as described in our previous publication (Schwenk et al., 2015). Validated algorithms were used to quantify spatio-temporal parameters of gait during walking (Aminian et al., 2002b, 2004; Lindemann et al., 2008; Najafi et al., 2009) and body sway (Najafi et al., 2010, 2015) during balance tests. Gait was assessed within a minimum of 25 steps under two conditions: 1) normal walk; and 2) fast walk. Gait outcome measures were steady-state spatio-temporal gait parameters, and included gait speed, stride length, gait cycle time, double support, and mid-swing velocity (see Table 1 for parameter definitions (Aminian et al., 2002a; Toosizadeh et al., 2015a,b; Zampieri et al., 2010)). Each participant performed four 30-s trials of balance assessment. In each trial, participants stood upright with their feet as close together as possible without touching, and with arms crossed. In the first two trials, participants were instructed to keep their eyes open (eyes-open trials), with no visual target specified. In the third and fourth trials, participants kept their eyes closed (eyes-closed trials). In each trial, the

center of gravity (CoG) was estimated following identical procedures reported in our earlier study (Najafi et al., 2010; Toosizadeh et al., 2015a). The balance outcome measures included body sway parameters: ankle sway, hip sway, CoG_{AP} (anterior-posterior sway), CoG_{ML} (medial-lateral sway), and CoG (see Table 1 for parameter definitions). Of note, two gait and balance conditions were performed (normal vs. fast walk and eye-open vs. eyes-closed) to investigate differences in capturing motor performance deficits due to LBP at two difficulty levels.

The TUG task was performed by asking participants to stand up from a standard chair, without arm assistance, walk 3 m, turn, walk back, and sit in the same chair (Podsiadlo and Richardson, 1991). In addition to the total TUG test duration, sensor-based spatio-temporal parameters were also measured including: duration of walking, postural transitions (i.e., sit-to-stand and stand-to-sit), turning, and trunk angular velocity during postural transitions and turning (Salarian et al., 2010; Toosizadeh et al., 2015b). Of note, all PROMS and objective motor performance assessments were performed by trained researchers (NT, HH, and TCY).

Table 1
Motor performance parameters definitions. A reference for calculation procedure is presented for each parameter.

	Definition	Reference
Gait		
Gait speed	Distance travelled divided by walking duration	Aminian et al. (2002a,b)
Stride length	Distance travelled by the same limb between two successive heel contacts (mean value across gait cycles)	Aminian et al. (2002a,b)
Gait cycle time	Time interval starts when one foot makes contact with the ground and ends when that same foot contacts the ground again (mean value across gait cycles)	Aminian et al. (2002a,b)
Double support	Duration of the initial and terminal double support (both feet in contact with the ground) as a percentage of the gait cycle time (mean value across gait cycles)	Aminian et al. (2002a,b)
Speed variability	Coefficient of variation (standard deviation divided by the mean) of gait speed among gait cycles	Aminian et al. (2002a,b)
Mid-swing velocity	Peak value of shins angular velocity during the swing phase (mean value across gait cycles)	Aminian et al. (2002a,b)
Postural balance		
Ankle sway	Product of range of ankle rotations in the anterior-posterior and medial-lateral direction	Toosizadeh et al. (2015a,b,c)
Hip sway	Product of range of hip rotations in the anterior-posterior and medial-lateral direction	Toosizadeh et al. (2015a,b,c)
COG_{AP}	Range of COG sway in the anterior-posterior direction	Najafi et al. (2010)
COG_{ML}	Range of COG sway in the medial-lateral direction	Najafi et al. (2010)
COG	Product of COG_{AP} and COG_{ML}	Najafi et al. (2010)
TUG		
S-St duration[a]	Required time to stand up from a chair	Zampieri et al. (2010)
Walk duration	Required time to walk 3 m forward and backward	Zampieri et al. (2010)
Turn duration[b]	Required time for the first and second turn	Zampieri et al. (2010)
St-S duration[a]	Required time to sit down on a chair	Zampieri et al. (2010)
Total duration	Required time to perform the entire TUG task	Zampieri et al. (2010)
Turning, S-St, or St-S peak velocity[a,b]	Maximum angular velocity of the trunk during turning, rising from a chair, or sitting on a chair	Zampieri et al. (2010)

COG: center of gravity.
AP: anterior-posterior.
ML: medial-lateral.
TUG: timed up & go.
S-St: sit-to-stand.
St-S: stand-to-sit.
ROM: range of motion.
[a] St-S and St-S transition were defined based on the change of trunk tilt in the sagittal plane.
[b] Turn transition was defined based on the change of trunk twisting angle.

2.5. Statistical analysis

Outcome measures and demographic characteristics were compared between DFO and healthy participants using analysis of variance (ANOVA) for continuous data or chi-square test for nominal outcomes. ANOVA models for outcome measure comparisons between two groups were adjusted by age, gender, and BMI, which were added as additional independent variables. To determine changes in outcome measures over the one-year follow-up, repeated measures ANOVA was used considering time as the within-subject factor; post hoc Tukey's honestly significant difference tests were performed for pairwise comparisons between outcomes at different measurement times. To account for missing data (prevent entire subject data removal due to lack of a data point), a linear mixed-effect model was selected instead of univariate general linear model repeated measures analysis.

ANOVA tests, adjusted with age, gender, and BMI were used to assess differences in baseline motor performance and pain level between those who benefited from spinal injection (reduced pain score within one or three months follow-up), and those who did not benefit from the treatment. If participants reported an immediate pain relief after injection, but the pain score increased within one month follow-up, they were still considered as those who benefitted from the injection. The one month data collection time was selected, because overall, the best motor performance and the lowest pain level were observed in one-month follow-up (see results below). Further, pain relief was considered as the target outcome for treatment success assessment, rather than other subjective and motor performance measures, because it has been commonly used for this purpose (Ashraf et al., 2015; Cohen et al., 2007).

Correlations between pain at the moment of measurements and motor performance parameters (each gait, balance, and TUG parameter) were assessed using linear regression-ANOVA models and reported as Pearson correlations (r values). A summary of results is presented as means (standard deviation - SD or standard error - SE). All analyses were done using JMP (Version 11, SAS Institute Inc., Cary, NC), and statistical significance was concluded when $P < 0.05$.

3. Results

3.1. Participants

Thirty DFO participants and 10 healthy controls were recruited. Mean (SD) age and BMI of DFO participants were 50 (14) years and 32.5 (6.6) kg/m^2, respectively, and 16 (53%) were male. Corresponding values for healthy participants were 46 (15) years and 25.2 (4.1) kg/m^2, and 4 (40%) were male. Overall, DFO participants were 32% heavier than healthy individuals. Of note, all statistical comparisons between DFO and healthy participants were, therefore, adjusted with BMI. Twenty-four (80%) of the DFO participants were also diagnosed with degenerative disk disorder. Detailed sociodemographic information is reported in Table 2. Of the 150 overall sessions, 45 (30%) were not completed, among which 23 (15%) were for the one-year follow-up sessions. The reason for missing data was mainly reoccurrence of LBP and second injections.

3.2. Changes in PROMs following spinal injection

Pain and Oswestry reports revealed significant improvements one month after spinal injection; average pain and Oswestry scores

Table 2
Mean (standard deviation or percentage) values of participant sociodemographic information. A significant between-group difference is indicated by the asterisk symbol.

	DFO	Healthy	*P*-value[†]	CI (lower)	CI (upper)	Effect size
Demographic characteristics						
Number (% of total)	30 (75%)	10 (25%)	–	–	–	–
Male, n (% of the group)	16 (53%)	4 (40%)	0.46	−0.45	1.03	–
Age, years	50 (14)	46 (15)	0.36	−7.76	2.86	0.28
Stature, cm	172 (11)	169 (11)	0.39	−5.81	2.33	0.27
Body mass, kg	96.8 (24.5)	73.4 (18.4)	<0.01*	−20.78	−3.87	1.28
BMI, kg/m^2	32.5 (6.6)	25.1 (4.6)	<0.01*	−5.88	−1.38	1.29
Subjective clinical measures						
Pain at baseline prior to injection, 0–10 scale	5.85 (2.35)	0.20 (0.42)	<0.0001*	−4.00	−2.16	3.35
Average pain two weeks prior to injection, 0–10 scale	7.07 (2.33)	0.60 (1.07)	<0.0001*	−4.30	−2.37	3.57
Oswestry, percentage	43.9 (16.0)	–	–	–	–	–
SF-12, PCS	28.1 (8.5)	54.6 (3.3)	<0.0001*	10.03	16.60	4.11
SF-12, MCS	48.6 (11.4)	55.0 (3.5)	0.35	−2.46	6.73	0.76
Short FES-I, 7-28	15.5 (6.8)	7.2 (0.6)	<0.01*	−6.50	−1.02	2.01
Lumbar spine diagnoses						
Facet osteoarthropathy, n	30	NA	NA	NA	NA	NA
Degenerative disk, n	24	NA	NA	NA	NA	NA
Spondylolysis, n	1	NA	NA	NA	NA	NA
Straightening of lordosis, n	8	NA	NA	NA	NA	NA
Hypertrophy of ligaments, n	2	NA	NA	NA	NA	NA
Foraminal narrowing	6	NA	NA	NA	NA	NA
Mild fracture, n	1	NA	NA	NA	NA	NA
Scoliosis, n	1	NA	NA	NA	NA	NA
Spinal fusion, n	4	NA	NA	NA	NA	NA

DFO: degenerative facet osteoarthropathy.
CI: confidence interval.
BMI: body mass index.
PCS: physical health composite scale.
MCS: mental health composite scale.
FES-I: Falls Efficacy Scale-International.
NA: not available.
[†] *P*-value is adjusted with age, gender, and BMI.

improved by 51% and 24%, respectively (Table 3 and Fig. 1). However, compared to baseline, no significant change was observed in the SF-12 health survey and short FES-I fall risk assessments in any of the follow-up measurements.

3.3. Changes in motor performance following spinal injection – Comparison with healthy participants

Motor performance measures were all collected within a range of ~20 to ~30 min, depending on the participants' adherence to instructions and technical problems during data collections. All motor performance parameters were significantly different between DFO patients and the healthy group (Table 4 and Fig. 2). Similar to PROMs, significant improvements, as compared with the healthy group (i.e., closer to healthy group average values), were observed in gait, balance, and TUG parameters (Table 4 and Fig. 2). Results showed that although immediate improvement in overall motor performance was evident, improvement was most noticeable in one-month post-injection measurements for almost all parameters. For some TUG parameters including walk duration, turn duration, stand-to-sit duration, and turn and sit-to-stand peak velocity, maximum improvement was observed in the three-month follow-up data. After the first or third months, motor performance deteriorated back toward baseline levels for most of gait, balance, and TUG parameters.

Among the assessed parameters, most improvements were observed in walking agility (gait speed, gait cycle time, mid-swing velocity) and stride length among gait parameters (6% change on average among conditions after one month, $P < 0.05$), hip sway within balance tests (58% reduction on average among condition after one month, $P < 0.01$), and turning velocity within the TUG test (28% faster turning performance after three months, $P < 0.02$ - Table 4 and Fig. 2). Several measures of motor performance within gait and TUG, and especially balance, demonstrated no improvement immediately following the spinal injection (Table 4).

Comparison between testing conditions suggest that motor performance improvements after spinal injection were better highlighted

Table 3
Changes in patient-reported outcome measures with time. Mean (standard deviation) values are presented. A significant effect of time on outcome measures is indicated by the asterisk symbol.

Subjective clinical measures	Baseline	Immediate FU[a]	One-month FU	Three-month FU	One-year FU	*P*-value
Pain at the moment, 0–10 scale	5.78 (2.34)	2.83 (2.71)	2.83 (2.73)	5.50 (3.00)	4.45 (3.08)	<0.0001*
Average pain in two weeks, 0–10 scale	7.07 (2.33)	–	3.69 (3.14)	5.96 (2.51)	5.65 (3.37)	<0.0001*
Oswestry, percentage	43.9 (16.0)	–	33.2 (18.5)	37.2 (14.2)	36.7 (18.4)	<0.01*
SF-12, PCS	28.2 (8.5)	–	34.5 (12.7)	32.3 (7.0)	32.7 (10.1)	0.08
SF-12, MCS	48.6 (11.4)	–	50.7 (10.8)	48.0 (13.2)	48.3 (12.5)	0.38
Short FES-I, 7-28	15.5 (6.8)	–	14.2 (5.7)	13.6 (5.1)	14.8 (5.2)	0.23

FU: follow-up.
PCS: physical health composite scale.
MCS: mental health composite scale.
FES-I: Falls Efficacy Scale-International.
[a] Immediate FU measures are not reported for several outcome measures, since they involve questions regarding the prior two weeks.

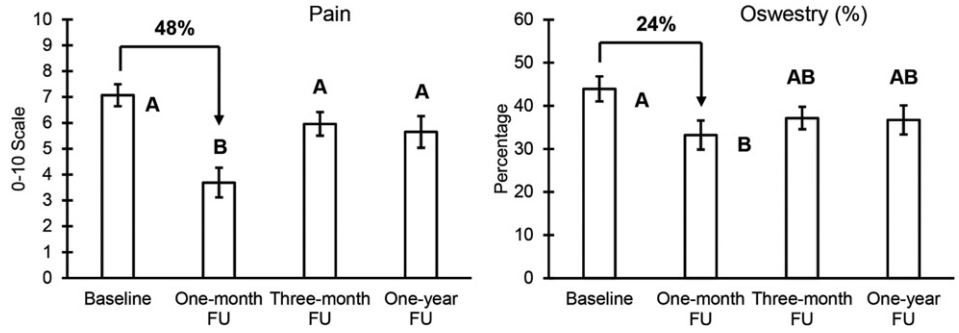

Fig. 1. Changes in pain (average pain in two weeks) and Oswestry scores by time. Mean values and standard errors are presented. Post-hoc results are illustrated using alphabetic grouping.

within normal compared to fast walking (Fig. 2). Among balance parameters, improvements were more pronounced within the eyes-open condition when compared to the eyes-closed condition (Fig. 2).

3.4. Differences in spinal injection results among DFO patients

Among our DFO sample, 8 (27%) participants received no noticeable pain relief even one month after the injection. No significant difference was observed in age, gender, and BMI, as well as baseline pain score and other health and disability questionnaires between DFO participants who had and those who did not have pain relief ($P > 0.26$). However, comparison between DFO subgroups (responders versus non-responders) showed that, overall, better baseline motor performance led to better spinal injection results in terms of pain relief. When adjusted for age, gender, and BMI, only turning velocity (and accordingly total TUG duration) within the TUG test was significantly different between two groups (Fig. 3).

3.5. Correlations between pain and motor performance

Significant correlations were observed between pain at the moment of measurements and gait parameters that represent walking agility, including gait speed ($r = 0.26$–0.36, $P < 0.02$), gait cycle time ($r = 0.32$–0.42, $P < 0.01$), and mid-swing velocity ($r = 0.39$–0.49, $P < 0.001$). However, no significant correlation was observed between pain measures and stride length or double support in any walking condition ($P > 0.07$). Comparing pain and balance behaviors demonstrated significant increases in body sway with pain, which were apparent across all balance parameters within both eye-open and eyes-closed conditions ($r = 0.22$–0.34, $P < 0.03$). For the above correlations, no noticeable difference was observed between testing conditions. Compared to gait and balance, weaker correlations were observed between pain measures and TUG parameters. Only sit-to-stand, stand-to-sit, walking duration, and total TUG durations were significantly less in those who reported less pain at the time of measurements ($r = 0.24$–0.26, $P < 0.02$).

4. Discussion

4.1. Alterations in motor performance and pain following spinal injection

Given our follow-up measurement timing, motor performance showed maximum improvements in one or three months after spinal injections; motor performance deteriorated after these maximum

Table 4
Changes in objective motor performance measures by time. Mean (standard deviation) values are presented. Due to similarities in changes between conditions results are reported only for normal walk and eye-open balance tests. A significant effect of time on outcome measures was indicated by the asterisk symbol.

Objective measures	Healthy	Baseline	Immediate FU	One-month FU	Three-month FU	One-year FU	*P*-value[†]
Gait speed, m/s	1.29 (0.18)	1.02 (0.22)	1.09 (0.21)	1.15 (0.17)	1.06 (0.17)	1.06 (0.13)	0.01*
Stride length, m	1.44 (0.15)	1.24 (0.18)	1.27 (0.16)	1.32 (0.13)	1.23 (0.13)	1.22 (0.11)	<0.01*
Gait cycle time, s	1.15 (0.09)	1.22 (0.12)	1.18 (0.12)	1.16 (0.12)	1.18 (0.09)	1.18 (0.07)	<0.05*
Double support, %	23.8 (3.5)	26.3 (4.4)	26.0 (4.1)	26.2 (5.0)	25.9 (6.0)	26.7 (5.6)	0.72
Speed variability, %	2.65 (1.67)	2.72 (1.97)	2.43 (1.49)	2.18 (1.11)	2.42 (0.84)	2.39 (0.89)	0.72
Mid-swing velocity, deg/s	363 (31)	309 (50)	325 (52)	339 (44)	318 (60)	324 (40)	0.01*
Ankle sway, deg^2	0.35 (0.20)	1.60 (1.99)	1.57 (1.57)	0.70 (0.67)	1.52 (1.81)	1.59 (2.19)	0.28
Hip sway, deg^2	0.40 (0.23)	1.22 (1.24)	1.15 (0.79)	0.45 (0.31)	0.90 (0.74)	0.63 (0.66)	0.03*
COG_{AP}, cm	0.21 (0.05)	0.50 (0.33)	0.51 (0.33)	0.37 (0.21)	0.44 (0.19)	0.40 (0.23)	0.34
COG_{ML}, cm	0.23 (0.08)	0.44 (0.19)	0.44 (0.18)	0.29 (0.12)	0.36 (0.15)	0.34 (0.12)	<0.01*
COG, cm^2	0.05 (0.27)	0.27 (0.32)	0.27 (0.31)	0.12 (0.12)	0.18 (0.18)	0.17 (0.18)	0.19
S-St duration, s	1.17 (0.21)	2.03 (1.01)	1.71 (0.63)	1.75 (0.37)	1.78 (0.66)	2.00 (0.32)	0.27
Walk duration, s	2.63 (0.57)	5.25 (1.79)	4.31 (1.77)	4.62 (1.13)	4.19 (1.16)	5.38 (1.41)	<0.01*
Turn duration, s	1.78 (0.42)	3.20 (1.00)	3.05 (1.00)	2.54 (0.75)	2.30 (0.81)	2.77 (0.62)	<0.0001*
St-S duration, s	1.37 (0.16)	2.83 (1.22)	2.65 (1.24)	2.35 (0.59)	2.24 (0.76)	2.60 (0.66)	0.13
Total TUG duration, s	6.52 (0.73)	12.10 (4.24)	10.13 (2.87)	9.10 (2.41)	10.21 (4.03)	10.69 (3.23)	<0.001*
Turning peak velocity, deg/s	358 (81)	202 (50)	208 (59)	219 (65)	223 (65)	184 (86)	0.02*
S-St peak velocity, deg/s	182 (57)	116 (40)	109 (40)	121 (42)	148 (71)	132 (65)	0.06
St-S peak velocity, deg/s	171 (50)	113 (59)	138 (69)	148 (62)	120 (43)	115 (62)	0.31

FU: follow-up.
COG: center of gravity.
AP: anterior-posterior.
ML: medial-lateral.
S-ST: sit-to-stand.
ST-S: stand-to-sit.
TUG: timed up & go.
[†] *P*-value for the effect of time on motor performance changes among DFO participants; all comparison of outcome measures between DFO baseline and healthy control showed significant difference ($P < 0.05$), except speed variability ($P = 0.86$), ankle sway ($P = 0.11$), and COG ($P = 0.09$).

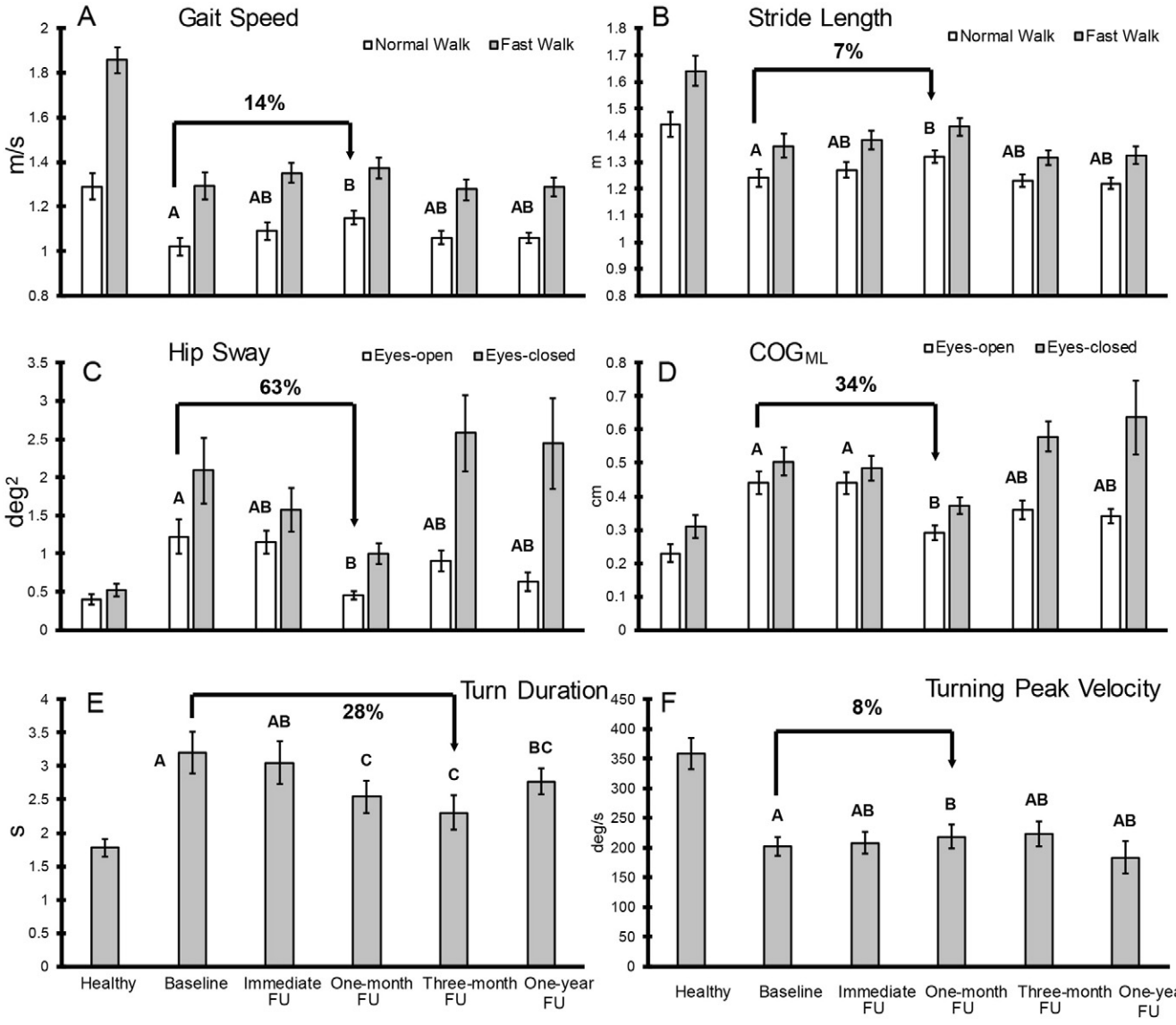

Fig. 2. Changes in motor performance with time. Mean values and standard errors are presented for the most sensitive parameters within gait, balance, and TUG. Post-hoc results are illustrated using alphabetic grouping. (FU: follow-up.)

points toward baseline values (Table 4 and Fig. 2). Interestingly, this observation was in disagreement with subjective pain reports, where there was a significant pain reduction immediately after injection with a similar reduction of ~50% as observed one month after the injection. This suggests that patients' perceived pain reduction immediately after spinal injection; however, the pain relief was not reflected in a significant immediate improvement in motor performance. No study, to the best of our knowledge, has investigated changes in motor performance using objective methods including gait and balance following spinal injection. In one study, daily physical activities were assessed

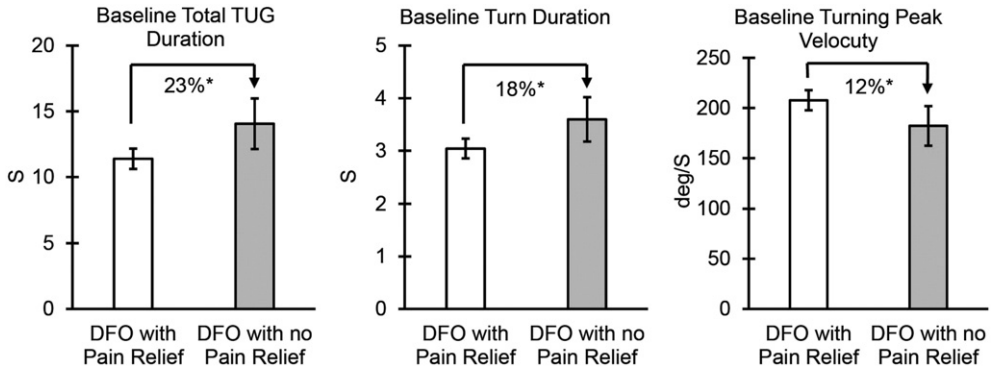

Fig. 3. Differences in baseline TUG parameters among DFO participants with and without pain relief following spinal injection. The asterisk symbol represents a significant difference.

within seven days monitoring prior to and following spinal injection using accelerometers (Tomkins-Lane et al., 2012). In agreement with our observations here, results from this study revealed that although participants perceived pain relief and improvements in physical function based on questionnaires, the objective evaluation showed no significant improvement in the daily physical activities (Tomkins-Lane et al., 2012). One possible reason for the observed disagreement between subjective pain report and objective motor performance might be due to the fact that these patients have lived with LBP for a long time. Therefore, the obligatory learned behaviors, including defective gait and balance patterns, take time to adjust. Of note, within our sample, balance performance showed the least immediate improvements after treatment (Table 4 and Fig. 2).

Sustainability of motor performance improvements after spinal injection has not been assessed previously. Results from subjective reports, however, suggest that pain relief may be maximum after one month (Benzon, 1986; Yun et al., 2012), three months (Leung et al., 2015), or even one year (Carette et al., 1991; Manchikanti et al., 2015) when utilizing different types of spinal injection as treatments for LBP. Based on our sample, effectiveness of spinal injection on pain relief (and subsequent motor performance improvements) varies among participants. For instance, two participants showed sustained pain relief even in one-year follow-up assessments, while for most of our DFO sample, LBP reoccurred in one month after the treatment.

4.2. Association between baseline motor performance and pain relief

Our results suggest that participants with better baseline motor performance, more likely benefit from spinal injections in terms of pain relief. Although no study has explored pre-treatment motor performance in patients with LBP, previous pain reports suggest that those with severe pain benefit less from spinal injections (Ashraf et al., 2015; Marks et al., 1992). Furthermore, long duration of LBP prior to spinal injection has been correlated with treatment failure (Cohen et al., 2007). In our sample, however, reported baseline pain was not associated with treatment success, probably due to our small sample size. Interestingly, within our sample, and other previously published work (Cohen et al., 2007), age, gender, and BMI are not associated with spinal injection treatment success.

Among measured motor performance within the current study, baseline turning velocity demonstrated the strongest association with spinal injection success. Previous studies showed that the highest loads are imposed on facet joints when the spinal column is exposed to axial rotation or asymmetric loading (Schmidt et al., 2008; Shirazi-Adl, 1991). With an assumption that more axial rotation or asymmetric loading are imposed to spine when performing the turning task within the TUG test, we suggest that turning could better highlight motor performance deficits in our DFO patients. This is in agreement with a previous study which reported facet loading within the rotation of the lumbar spine as the best predictor variable of success in DFO facet denervation treatment (Cohen et al., 2007).

Overall, based on our observations here, it may be possible to improve patient selection for spinal injection based on pre-treatment motor performance evaluations. Although criteria of success and failure have been examined for several type of spinal surgery or cervical injections (Airaksinen et al., 1997; Ferrante et al., 1993; Snider et al., 1999), surprisingly, variables associated with spinal facet treatment have not been critically studied (Cohen et al., 2007). Lack of proper identification of injection candidates may compromise the success rate of treatment, impose an unnecessary cost on patients, and also expose patient to additional risks. Therefore, understanding predictors of spinal injection outcomes based on patient-specific evaluations requires more comprehensive investigations. Although current results demonstrated promise for using motor performance assessments to predict spinal injection outcomes, findings should be interpreted cautiously and confirmed in future studies. Specifically, no prediction model regarding adverse spinal injection outcomes using baseline motor performance was developed, and accordingly no cut-offs of motor performance parameters for predicting treatment success/failure was determined.

4.3. Association between objective measures and subjective pain reports

Our findings suggest that with increasing levels of pain, impairments in motor performance become more noticeable, especially for gait speed, body sway during balance, and postural transitions during TUG. In several previous studies compromised gait, balance, chair stands, and other motor performance behaviors due to LBP have been reported (Mientjes and Frank, 1999; Mok et al., 2004; Reid et al., 2005). Although literature supports the fact that people with LBP have a compromised motor performance, interestingly, comparing motor performance and the level of pain at the time of measurements within our sample showed weak to moderate correlations. This observation suggests that pain perception may not perfectly correlate with motor performance, which may result from psychological factors that can influence patients' judgement. Therefore, objective motor performance assessments may provide additional information for evaluating spinal injection outcomes.

4.4. Limitations and future directions

One limitation of this study is the relatively large number of participants with missing data, especially in the one-year follow-up sessions. Most these patients had second injections after the effect of first injection had faded away, and, therefore, were excluded for following measures to minimize potential confoundings. Current results regarding one-year follow-up data should be, therefore, interpreted cautiously. Second, the current study was not a randomized control trial, hence the placebo effect of spinal injection on motor performance improvements needs further investigation. Also, previous work suggest that often patients with acute back pain heal faster when they obtain no treatment and continue daily activities, compared with those who are assigned to bed rest or back-mobilizing exercise treatments (Malmivaara et al., 1995). Since no control group without treatment was considered for the current study, no conclusion can be made regarding faster reduction in pain and enhancement in motor performance using spinal injection compared to natural healing of pain without treatment. Moreover, to generalize findings of the study, all adults over 18 years old were recruited, and we also did not control for obesity. Accordingly, although all statistical analysis were adjusted for age and BMI, future studies are required to further address the influence of age and BMI on motor performance improvements following spinal injections.

4.5. Clinical implications

Outcome measurement is a very important issue for any clinical intervention, and how to measure outcomes has always been a matter of debate. This study, for the first time, showed that innovative wearable sensor technology for measuring motor performance can provide a feasible option for health outcome measurement. In addition, assessing motor performance prior to spinal injection may provide selection criteria to determine which group of patients benefit most from spinal injection. Finally, most of the motor performance parameters were significantly improved up to three months after injection. Consideration of repeated injections should be explored in future work.

5. Conclusions

Results from the current study, for the first time, revealed that spinal injection can temporarily (up to three months) improve motor performance measured objectively by gait, balance, and TUG tests. Maximum improvements in motor performance were observed in one or three months after the treatment, depending on the type of test. Comparing

subjective pain reports and objective motor performance assessments, antithetically demonstrated only weak to moderate correlations, as well as disagreement between immediate patients' reported pain relief and gradual improvements in motor performance. Although no significant difference was observed in demographic characteristics and pain among participants who had successful and unsuccessful treatment outcomes, baseline motor performance was better for those who had successful treatment in terms of pain relief. The best motor task that was associated with spinal injection success was turning speed. Lastly, within the current study we demonstrated the feasibility of performing several motor performance assessments in the clinical setting within a limited time of <30 min. These findings show promises for enhancement of diagnosis and treatment evaluation based on objective criteria in addition to subjective patient-reported outcome measures.

Author contributions

Study conception and design: Toosizadeh, Dohm, and Najafi
Acquisition of data: Toosizadeh, Harati, Yen
Analysis and interpretation of data: Toosizadeh, Harati, Mohler, Dohm, and Najafi
Drafting of manuscript: Toosizadeh and Harati
Critical revision: Toosizadeh, Harati, Yen, Mohler, Mohler, Dohm, and Najafi
Obtaining funding: Dohm and Najafi

Conflicts of interest

None.

Sponsor's role

The sponsors had no role in the design or conduct of the study; collection, management, analysis, or interpretation of the data; or preparation, review, or approval of the manuscript.

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