Abstract

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Project Title: Movement coordination impairment in non-specific low back pain: Preliminary investigation of underlying neuromuscular mechanism associated with aberrant movement

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Introduction: Current evidences suggest that patients with non-specific low back pain (NSLBP) have altered lumbopelvic movement patterns. Physical therapists believe these changes were associated with changes in muscle activation patterns. However, these associations has not been systematically investigated. The purposes of this study were to determine: 1) the difference in lumbopelvic movement patterns between healthy individuals (CON) and patients with NSLBP (LBP), 2) the difference in lumbopelvic muscle activation patterns between CON and LBP, and 3) the association between lumbar and pelvic movement patterns and lumbopelvic muscle activation patterns.

Methods: Eight patients with NSLBP (age 29.4±5.2 years; 42.9% female; BMI 24.5±2.2 kg/m^2; Numeric pain rating scale 5.7±1.9; Oswestry disability index 19.7±7.5%), and 8 matched healthy individuals (age 27.7±5.0 years; 42.9% female; BMI 22.1±2.3 kg/m^2) were recruited in this study. Each subject performed 2 sets of 3 repetitions of active forward bend task, while motion and muscle activity data were simultaneously collected.

Results: Lumbopelvic motion data show trends, but exceeding 95% confidence minimal detectable difference. These trends demonstrate greater pelvic motion ($p = 0.057$), but less lumbar motion ($p = 0.232$) in LBP group. Bilateral gluteus maximus muscles were significantly less activated ($p < 0.05$) in LBP group. Significant association ($r = -0.79$, $p = 0.021$) was found between ipsilateral erector spinae muscle and lumbar motion, while moderate associations, but not statistical significance, were found between bilateral gluteus maximus muscle and lumbar velocity (ipsilateral: $r = -0.57$, $p = 0.140$; contralateral: $r = -0.55$, $p = 0.157$) in LBP group.

Discussion: Patients with NSLBP used different motion and muscle activation patterns during active forward bending. They had greater pelvic contribution, but less lumbar contribution. This could be caused by less activation of bilateral gluteus maximus muscles. The findings indicate that patients with NSLBP might use lumbar stiffening strategy to minimize shear force on the lumbar spine.

Implication: Clinical implication is that intervention for patients with NSLBP should be designed to modify lumbar and pelvic contributions through the activation of gluteus maximus muscle. This would minimize an excessive load on the lumbar spine and help in prevention of the recurrence of low back pain. Future study may incorporate our findings to refine the intervention that addresses lumbar and pelvic contribution, as well as muscle activation pattern.

Keywords: *Non-specific low back pain; Lumbopelvic movement pattern; Lumbopelvic muscle activation pattern.*

<u>วัตถุประสงค์</u>: จากหลักฐานทางวิชาการ พบว่า ผู้ป่วยโรคปวดหลังแบบไม่เฉพาะเจาะจงมีการเคลื่อนไหวของกระดูกสันหลังส่วนเอวและเชิงกรานที่เปลี่ยนแปลงไป นักกายภาพบำบัดเชื่อว่าการเปลี่ยนแปลงนี้มีความสัมพันธ์กับการเปลี่ยนแปลงการทำงานของกล้ามเนื้อ อย่างไรก็ตาม ความสัมพันธ์นี้ยังไม่การทดสอบอย่างมีระบบ ดังนั้น วัตถุประสงค์ของการศึกษานี้คือ 1) เพื่อหาความแตกต่างในรูปแบบการเคลื่อนไหวของกระดูกสันหลังส่วนเอวและเชิงกรานระหว่างคนปกติและผู้ป่วยโรคปวดหลัง, 2) เพื่อหาความแตกต่างในการทำงานของกล้ามเนื้อของทั้ง 2 กลุ่ม และ 3) เพื่อหาความสัมพันธ์ระหว่างรูปแบบการเคลื่อนไหวและการทำงานของกล้ามเนื้อ

<u>วิธีทดลอง</u>: ผู้ป่วยโรคปวดหลังจำนวน 8 คน (อายุ 29.4±5.2 ปี; เพศหญิง 42.9%; ดัชนีมวลกาย 24.5±2.2 kg/m^2; ระดับความปวด 5.7±1.9; แบบประเมินออสเวสทรี 19.7±7.5%) และผู้เข้าร่วมสุขภาพดี 8 คน (อายุ 27.7±5.0 ปี; เพศหญิง 42.9%; ดัชนีมวลกาย 22.1±2.3 kg/m^2) เข้าร่วมในการศึกษานี้ ผู้เข้าร่วมแต่ละคนก้มหลัง 2 รอบ ๆ ละ 3 ครั้ง โดยข้อมูลการเคลื่อนไหวและการทำงานของกล้ามเนื้อจะถูกบันทึกไว้ในเวลาเดียวกัน

<u>ผลการทดลอง</u>: ข้อมูลการเคลื่อนไหวของกระดูกสันหลังส่วนเอวและเชิงกราน แสดงให้เห็นแนวโน้มความแตกต่างที่มากกว่าค่าความคลาดเคลื่อนที่ระดับความเชื่อมั่น 95% โดยกลุ่มผู้ป่วยพบว่ามีการเคลื่อนที่ของเชิงกรานมากกว่า (p = 0.057) แต่การเคลื่อนที่ของกระดูกสันหลังส่วนเอวน้อยกว่า (p = 0.232) กล้ามเนื้อก้นทั้งสองข้างมีการทำงานที่น้อยกว่าในกลุ่มปวดหลัง (p < 0.05) นอกจากนี้ยังพบความสัมพันธ์อย่างมีนัยสำคัญ (r = -0.79, p = 0.021) ระหว่างกล้ามเนื้อหลังชั้นตื้นข้างที่ปวดกับการเคลื่อนที่ของกระดูกสันหลังส่วนเอว ในขณะที่พบความสัมพันธ์ระดับปานกลาง แต่ไม่มีนัยสำคัญทางสถิติ ระหว่างกล้ามเนื้อก้นทั้งสองข้างกับความเร็วในการเคลื่อนที่ของกระดูกสันหลังส่วนเอวในกลุ่มปวดหลัง (ข้างเดียวกับที่ปวด: r = -0.57, p = 0.140; ข้างตรงข้ามกับที่ปวด: r = -0.55, p = 0.157)

<u>สรุปและวิจารณ์ผล</u>: ผู้ป่วยโรคปวดหลังแบบไม่เฉพาะเจาะจง ใช้รูปแบบการเคลื่อนที่และการทำงานของกล้ามเนื้อที่เปลี่ยนแปลงในการก้มหลัง โดยผู้ป่วยจะก้มหลังโดยใช้เชิงกรานมากกว่ากระดูกสันหลังส่วนเอว ซึ่งอาจเป็นผลจากการทำงานของกล้ามเนื้อก้นทั้งสองข้างที่น้อยลง ผลการศึกษาชี้ให้เห็นว่า ผู้ป่วยใช้วิธีการเกร็งหลังให้แข็งเพื่อลดแรงเฉือนที่เกิดขึ้นบริเวณกระดูกสันหลังส่วนเอว

<u>ข้อเสนอแนะ</u>: การรักษาผู้ป่วยโรคปวดหลังแบบไม่เฉพาะเจาะจง ควรเน้นการปรับรูปแบบการเคลื่อนที่ของกระดูกสันหลังส่วนเอวและเชิงกรานผ่านทางการกระตุ้นกล้ามเนื้อก้น เพื่อที่จะลดแรงเฉือนที่เกิดขึ้นที่กระดูกสันหลังส่วนเอว ซึ่งอาจจะเป็นการช่วยป้องกันการเกิดซ้ำของอาการปวดหลัง การศึกษาในอนาคตอาจเป็นการออกแบบการรักษาที่เน้นการเคลื่อนที่ของกระดูกสันหลังส่วนเอวและเชิงกรานที่ถูกต้อง รวมไปถึงการปรับรูปแบบการทำงานของกล้ามเนื้อหลังและเชิงกราน

คำสำคัญ: โรคปวดหลังแบบไม่เฉพาะเจาะจง; รูปแบบการเคลื่อนไหวของกระดูกสันหลังส่วนเอวและเชิงกราน; รูปแบบการทำงานของกล้ามเนื้อกระดูกสันหลังส่วนเอวและเชิงกราน

Introduction

Low back pain (LBP) is a common health problem in many countries with high prevalence and recurrence rate (Andersson, 1999; Pengel, Herbert, Maher, & Refshauge, 2003). Non-specific low back pain (NSLBP) is assigned when a recognizable or known specific pathology cannot be identified (Waddell, 1987). NSLBP is accountable for approximately 85% of LBP (Carey, Garrett, & Jackman, 2000).

Current research studies demonstrate that patients with NSLBP have trunk neuromuscular control changes including altered lumbar spine and pelvis contribution, altered lumbopelvic muscle activation patterns, delayed muscle onset timing, as well as altered trunk muscle co-activation ratio (Hodges & Richardson, 1996; O'Sullivan, Twomey, Allison, Sinclair, & Miller, 1997; Silfies, Mehta, Smith, & Karduna, 2009; Teyhen, Flynn, Childs, & Abraham, 2007; Wong & Lee, 2004). In addition, persistence of these changes in trunk neuromuscular control is attributable to the perpetuation and recurrence of low back episode which could be a financial burden for a health care system (Dagenais, Caro, & Haldeman, 2008; Hides, Richardson, & Jull, 1996; Kjaer, Bendix, Sorensen, Korsholm, & Leboeuf-Yde, 2007).

Clinicians suggest that clinical observation of aberrant movement patterns during active trunk forward bending in patients with NSLBP are associated with trunk neuromuscular control deficits (Biely, Silfies, Smith, & Hicks, 2014; O'Sullivan, 2005; Panjabi, 2003; Van Dillen et al., 2003). Aberrant movement patterns in trunk forward bending are defined as a pattern that deviates from the typical or expected symmetrical, appropriately coordinated and controlled movement pattern.

In addition, lumbopelvic muscles including transverse abdominis (TA), lumbar multifidus (LM), lumbar erector spinae (ES), and gluteus maximus (GM) muscles have been proposed as key contributors that provide dynamic stability during functional movement (Hebert, Koppenhaver, Magel, & Fritz, 2010; Hides, Richardson, & Jull, 1996; Hodges & Richardson, 1996; Kiesel, Underwood, Mattacola, Nitz, & Malone, 2007; O'Sullivan, Twomey, & Allison, 1998). Researchers have demonstrated that TA and LM activities were altered in patients with NSLBP, and patients with NSLBP demonstrated GM weakness (Hodges & Richardson, 1996; Jacobs, Henry, Jones, Hitt, & Bunn, 2011; Mehta, Cannella, Smith, & Silfies, 2010; Panjabi, 2003; Silfies, Mehta, Smith, & Karduna, 2009; Silfies, Squillante, Maurer, Westcott, & Karduna, 2005; White & Panjabi, 1990). These functionally-impaired muscles may be associated with aberrant movement patterns observed in patients with NSLBP.

Kinematics in conjunction with a dynamic systems approach has been widely utilized for investigating human movement patterns (Esola, McClure, Fitzgerald, & Siegler, 1996; Gatton & Pearcy, 1999; Hasebe et al., 2013; Lee & Wong, 2002; McClure, Esola, Schreier, & Siegler, 1997; Wong & Lee, 2004). Evidences support the utility of this method to qualitatively and quantitatively characterize trunk forward bend movement, as well as demonstrate differences in spine and pelvic movement patterns between patients with NSLBP and healthy individuals (Wattananon, Ebaugh, Biely, Smith, Hicks, & Silfies, 2017; Wattananon, Intawachirarat, Cannella, Sung, & Silfies, 2017). In addition, several researchers have demonstrated changes in muscle activity including onset timing, activation pattern, and co-contraction ratio in patients with NSLBP using electromyography (EMG) (Hodges & Richardson, 1996; Jacobs et al., 2011; Mehta et al., 2010; Panjabi, 2003; Silfies et al., 2009; Silfies et al., 2005; White & Panjabi, 1990). However, the association between underlying lumbar and pelvic movement patterns and lumbopelvic muscle activation patterns during active forward bending in patients with NSLBP has not been systematically investigated.

Therefore, the purposes of this study were to: 1) determine the difference in lumbar and pelvic movement patterns between healthy individuals (CON) and patients with NSLBP (LBP), 2) determine the extent of differences in lumbopelvic muscle activation patterns (TA, LM, ES, and GM) between CON, and LBP, and 3) determine association between lumbar and pelvic movement patterns and lumbopelvic muscle activation patterns. We hypothesized that patients with NSLBP would have altered lumbar and pelvic movement pattern, and lumbopelvic muscle activation pattern. We also further hypothesized that there would be associations between lumbar and pelvic movement patterns and lumbopelvic muscle activation patterns. An enhanced knowledge of this study would provide a significant step toward investigation of the underlying neuromuscular mechanism, and the ability of exercise intervention to restore lumbar and pelvic movement pattern and lumbopelvic muscle activation pattern. The long-term outcome of this research would help in improvement of physical therapy intervention specific to patients with NSLBP, thereby optimizing clinical outcomes and preventing recurrence of symptoms.

Methods

Subjects

Eight patients with NSLBP between the ages of 21 and 65, and 8 age-, sex-, and BMI-matched healthy individuals were recruited in this study. Additional inclusion

criteria for patients with NSLBP included current episode of back pain less than 3 months that caused them to seek medical intervention and did not receive any intervention involving in core stability in the last 6 months. Subjects were excluded if they have clinical signs of systemic disease, definitive neurologic signs including weakness or numbness in the lower extremity, previous spinal surgery, osteoporosis, severe spinal stenosis, and/or inflammatory joint disease, pregnancy, any lower extremity condition that would potentially alter trunk movement in standing, vestibular dysfunction, extreme psychosocial involvement, and body mass index (BMI) greater than 30 kg/m^2. The institutional review board approval from university was obtained (COA No. 2015/050.3004) prior to data collection.

Instrumentations and measures

Electromagnetic tracking system (3D Guidance trakSTAR, Ascension Technology Corporation) was used for motion data collection. Criteria-related validity with known quantity has been reported by manufacturer. Coefficient of multiple determination demonstrated excellent (R^2 = 0.98) test-retest reliability of this system. Three sensors were attached to the subject at the following landmarks: 1) right femur (bony prominence of the right femoral lateral epicondyle); 2) pelvis (over the spinous process of S2); and 3) lumbar spine (over the spinous process of L1). These sensor placements are based upon recommendations of the International Society of Biomechanics (Wu et al., 2002). Tracking system collected data at 100 Hz. Previous work has demonstrated kinematics in conjunction with a dynamic systems approach can be used to quantify movement patterns that represent clinically observed aberrant movement patterns (Wattananon et al., 2017a; Wattananon et al., 2017b).

Electromyography (TeleMyo 2400R G2, Noraxon Inc.; common mode rejection ratio > 100 dB, input impedance > 100 MOhm, 500 gain) with pre-amplified bipolar electrodes (Kendall Medi-Trace 100, Kendall Inc.; Al/AgCl, disc-shaped, 1-cm diameter) was used to collect muscle activity from bilateral TA, LM, ES, and GM. Skin was lightly abraded using abrasive paper and cleaned using cotton with alcohol to lower the skin impedance. TA electrodes were placed at 2 cm. medial to ASIS and on inguinal line. LM electrodes were placed at 2 cm. lateral to L5 spinous process. ES electrodes were placed at 3 cm. lateral to L1 spinous process. GM electrodes were placed at midpoint between greater trochanter and the last sacral vertebrae (Silfies et al., 2005). Electrodes were placed parallel to the muscle fibers with inter-electrode distance of 2 cm. Analog EMG data were bandpass-filtered (10-1500 Hz), and differentially amplified to +/- 5 V.

Procedures

Each subject underwent the written informed consent process prior to data collection. Electromagnetic sensors and surface EMG electrodes were attached to the subject's body landmarks. Subjects were instructed to perform a modified Sorensen test at submaximal level (15% of body weight) to derive bilateral LM and ES reference voluntary contraction (RVC). We used these submaximal level to avoid pain aggravation which could change muscle activation pattern. In addition, subjects were asked to perform maximal contraction of hip extension in prone with 90° knee flexion position, and maximal abdominal hollowing in crook lying position to derive RVC for GM and TA, respectively. These RVC were further used to normalize EMG data for each muscle group. Subjects were instructed to perform 2 sets of 3 consecutive repetitions of forward bending movement. Motion and EMG data were simultaneously recorded.

Data reduction

Data reduction was performed using a customary LabVIEW program (National Instruments Corp.). Motion data were converted to segment angular rotations using Euler's angle in Cardan sequence (x, y, and z). Segment angular rotations include lumbopelvic motion (lumbar sensor respects to femur sensor), lumbar motion (lumbar sensor respects to pelvic sensor), and hip motion (pelvic sensor respects to femur sensor). These data were filtered using a dual-pass Butterworth (sampling frequency at 100 Hz with 2^{nd} order low pass frequency at 5 Hz). Maximal range of motion, time to maximal range of motion, maximal angular velocity, and time to maximal angular velocity for lumbopelvic segment (LPROM, LPT2PR, LPV, and LPT2PV), lumbar spine (LROM, LT2PR, LV, and LT2PV), and pelvis (PROM, PT2PR, PV, and PT2PV) for each repetition were derived. Averaged motion parameters across the first 3 repetitions and the last 3 repetitions were used to establish test-retest reliability and 95% confidence minimal detectable difference (MDD_{95})

EMG data were filtered using an independent component analysis to remove heart rate artifact. Heart-rate filtered EMG were further filtered using a band pass filter (2^{nd} order Butterworth high pass at 20 Hz and low pass at 400 Hz) and a band stop filter (2^{nd} order Butterworth at 50 Hz). These data were full wave rectified and underwent data smoothing using root mean square (RMS) with a time constant of 50 milliseconds. RVC data between 2 and 4 seconds was used to normalize muscle activity during forward bending task. However, our preliminary data analysis demonstrated that pain location in patients with NSLBP could change muscle activation patterns; therefore, we separately analyzed muscle groups by ipsilateral and contralateral to the pain location for main analysis. Ipsilateral (I) and contralateral (C)

peak EMG amplitudes for each muscle (ITA, CTA, ILM, CLM, IES, CES, IGM, and CGM) were derived. Similar to motion data, averaged EMG parameters across the first and last 3 repetitions were used to establish test-retest reliability and MDD_{95}.

Statistical analysis

Statistical analysis was performed using SPSS software version 21.0 (IBM Corp.). Intra-class correlation coefficients ($ICC_{3,3}$) were used to establish test-retest reliability of motion and EMG parameters, and MDD_{95} were further derived. Normality test was performed using Kolmogorov-Smirnov goodness-of-fit test. Independent t-tests were used to compare age, BMI, LPROM and LPV at baseline when data had normal distribution, and Mann Whitney's U test was used when data were non-normally distributed. In addition, chi-square test was used to determine the difference in sex ratios between groups at baseline. For motion data, a mixed design ANOVA with post-hoc pairwise comparisons with bonferonni adjustment was used to determine the lumbar and pelvic movement patterns between groups when data were normally distributed. Otherwise, non-parametric Wilcoxon's sign rank test was used to determine the difference between segments and Mann Whitney's U test was used to determine the difference between groups. For EMG data, independent t-tests were used to compare each muscle between groups when data were normally distributed; otherwise, Mann Whitney's U tests were used instead. To determine the association between, motion and muscle activity, Pearson's correlations were used when data had normal distribution, while Spearman's rank tests were used when data had non-normal distribution. Confidence level (α) was set at 0.05.

Results

Demographic data (Table 1) demonstrated no significant difference ($p > 0.05$) in age, sex, BMI, LPROM, and LPV between CON and LBP groups. Intra-class correlation coefficient ($ICC_{3,3}$) demonstrated excellent test-retest reliability ($ICC_{3,3}$ ranged between 0.901 and 0.997) of EMG and motion parameters, and 95% confidence minimal detectable difference (MDD_{95}) has been established (Table 2).

Motion data in both groups were normally distributed; therefore, mixed ANOVAs were used to determine the difference in lumbar and pelvic motion between groups. Results (Table 3 and Figure 1) demonstrated trend in interaction effect of Group*Segment ($F_{1,14} = 4.44$, $p = 0.054$, $\eta^2 = 0.24$), but significant main effect of Segment ($F_{1,14} = 27.70$, $p < 0.001$, $\eta^2 = 0.66$). Post-hoc simple comparisons (Table 4) in ROM between groups demonstrated trend ($p = 0.057$), but exceeded MDD_{95}, showing greater PROM in LBP group, while LROM in LBP group was less than CON group

exceeding MDD_{95}, but did not yield statistical significance. Simple within-group comparisons (Table 4) demonstrated significant greater PROM comparing with LROM in both CON (p = 0.043) and LBP (p < 0.001). Velocity result (Table 3 and Figure 2) demonstrated only significant main effect of Segment ($F_{1,14}$ = 6.02, p = 0.028, η^2 = 0.30). Post-hoc simple within-group comparisons (Table 4) demonstrated significant greater PV comparing with LV (p = 0.034) in only LBP group.

EMG data were not normal distributed (p > 0.05); therefore, non-parametric Mann Whitney's U tests were performed to determine the difference in lumbopelvic muscle activation between groups. Results demonstrated significant lower activation of both IGM and CGM in LBP group comparing with CON (p = 0.021 and 0.038, respectively); however, only median IGM exceeded MDD_{95} (Table 5).

Because EMG data were not normal distribution even though motion data were normal distribution, non-parametric Spearman's rank tests were used to determine correlation between lumbopelvic movement patterns and muscle activation patterns. Correlation results (Table 6) demonstrated weak negative association trends between both IGM and CGM and PROM (r = -0.45, p = 0.080 and r = -0.43, p = 0.098, respectively). In addition, a weak negative association trend (r = -0.48, p = 0.060) was found between IES and LROM. However, when separately analyzing LBP group (Table 7), significant strong negative association (r = -0.79, p = 0.021) was found between IES and LROM, while moderate negative associations, but not statistical significance, were found between CLM and LROM (r = -0.55, p = 0.160), IGM and LV (r = -0.57, p = 0.140), and CGM and LV (r = -0.55, p = 0.157). In addition, moderate positive association, but not statistical significance, were found between IGM and LT2PR (r = 0.52, p = 0.183), and IGM and PT2PR (r = 0.55, p = 0.160). Similarly, when separately analyzing CON group (Table 8), significant strong negative associations were found between ITA and LV (r = -0.79, p = 0.021), ILM and LV (r = -0.95, p < 0.001), IGM and LV (r = -0.79, p = 0.021), and CGM and LV (r = -0.83, p = 0.010), while moderate negative associations, but not statistical significance, were found between CTA and LV (r = -0.50, p = 0.207), CLM and LV (r = -0.62, p = 0.102), IES and LV (r = -0.50, p = 0.207), and CGM and LV (r = -0.69, p = 0.058). In addition, moderate negative associations, not statistical significance, were found between IES and PT2PR (r = -0.50, p = 0.207), and CLM and LT2PV (r = -0.50, p = 0.207).