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Research Article

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The Effects of Maintained Muscle Contraction of Abdominal and Pelvic Floor Muscles on 3D Pelvic Stability in Individuals with Chronic Low Back Pain During Gait

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| Abstract |

PURPOSE: This study was designed to investigate the effects of keeping contraction of abdominal and pelvic floor muscles on 3D pelvic stability in individuals with non-specific chronic low back pain (CLBP) during normal speed walking.
METHODS: The subjects were 20 adults with CLBP deformity and had moderate pain intensity of the visual analog scale. A three-dimensional camera capture system was used to collect kinematic pelvic motion data with and without contraction of the abdominal and pelvic floor muscles during gait. The subjects were asked to walk on a walkway in the lab room and they were attached 40 reflective markers to their pelvic segment and lower extremities. A Visual3D Professional V6 program and Vicon Nexus software were used to analyze 3D pelvic kinematic data.
RESULTS: There were significant differences between with and without contraction of the abdominal and pelvic floor muscles of the pelvic depression and the total pelvic motion in coronal plane during gait ($p < .05$). However, there were no significant differences in any of the maximal motion of the pelvic segment in sagittal and transverse motion plane according to the different muscle contraction conditions ($p > .05$).
CONCLUSION: The results of this study suggest that maintaining co-contraction of the abdominal and pelvic floor muscles in individuals with CLBP increased pelvic stability and contributed to preventing excessive pelvic movements during gait.

Key Words: Abdominal muscles, Gait, Low back pain, Pelvic motion

Ⅰ. Introduction

Low back pain is the primary cause of work absence and disability in industrialized societies [1-2]. Chronic low back pain (CLBP) is defined as back pain and disability continuing for more than 3 months and approximately 10-20% of individuals with low back pain progress CLBP [3]. In particular, the pathophysiologic causes of CLBP, which occur in the majority of patients with low back pain,

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cannot be clearly identified [4]. CLBP individuals had decreased muscle strength in the core abdominal muscles, muscle asymmetry in the both deep abdominal muscles, and decreased proprioceptive sensory function compared with the control group without low back pain [5,6]. These factors negatively affect the stability of the lumbar spine and pelvic segment, causing the progression and recurrence of CLBP [5-7].

It has been reported that muscle weakness of the transversus abdominis (TA) among abdominal muscles elicits lumbar instability and has a significant relationship with the occurrence of low back pain [6]. Therefore, a selective intensive training on TA for improving trunk stability and treating low back pain is required. In addition, as the pelvic floor muscles (PFM) are known to play an important role in stabilizing the abdomen and pelvis during various daily activities such as walking, they should be considered together within the selectively intensive training of the TA muscles [7]. In general, in patients with chronic non-specific low back pain, it is known that muscle weakness of the TA and PFM was the main cause rather than the tightness of the lumbar back extensors, which is often seen in acute low back pain [4-6]. PFM is composed of various muscles, ligaments, and fascia between the pubis and coccyx, and blocks the outside of the floor of the abdominopelvis cavity and supports the structures inside the pelvic cavity [5]. In addition, PFM stabilizes the pelvis between the two feet in standing, and plays a role in maintaining balance with the center of gravity during gait [8,9]. In previous studies, a contraction training of PFM was accompanied by contraction of the abdominal muscles, which was called 'abdominal hollowing' or 'abdominal bracing' [10,11].

The pelvic segment connects the trunk to the lower extremities, supports the upper body weight when sitting, and transfers weight from the spine to the lower extremities when standing. Therefore, the pelvic segment plays a role as a linker and a coordinator of the upper and lower body to maintain efficient walking ability. However, pelvic instability during gait negatively affects various biomechanical walking parameters [12-14]. Although it has been verified in many previous studies that contraction of the PFM increases intra-abdominal pressure and elicits co-activation of the TA muscle, which contributes to stabilization of the lumbar spine [5,11], verification of the effects of co-activation of abdominal and PFM on 3D pelvic mobility in individuals with CLBP during gait is not yet clear and insufficient.

Therefore, the purpose of this study was to investigate the effect of co-activation of the TA and PFM on pelvic kinematics through 3D gait analysis in individuals with CLBP during gait.

Ⅱ. Methods

1. Participants

A sample size was calculated based on an estimated effect size derived from Kim [15] who verified the effect of orthotic shoe insoles on pelvic kinematics in individuals with leg length discrepancy related to CLBP and a sample size of 20 was determined to be sufficient to identify significant effects. The participants in this study were twenty adults (10 males and 10 females) with CLBP deformity. Subject inclusion criteria were chronic nonspecific low back pain lasting at least 3 months and a visual analog scale (VAS) score of at least moderate (4-7 points) [16]. The mean and standard deviation of VAS score was 5.35±1.18 point and illness duration of CLBP was 16.5±7.8 months, respectively. Subjects were excluded if they had specific pathologic conditions such as spinal inflammation, malignancy, or undergone back surgery.

All participants fully understood the aim and assessment process of the study and provided written informed consent. This study was approved by the Institutional Review Board of Jeonju University (jjIRB-210714-HR-2021-0718). The

Table 1. General Characteristics of Subjects (N=20)

Characteristics	Mean ± SD
Gender	Male: 10, Female: 10
Age (years)	23.53 ± 1.82
Height (cm)	168.51 ± 7.82
Weight (kg)	66.58 ± 18.00
Visual analog scale (0-10)	5.35 ± 1.18

general characteristics of participants are shown in Table 1.

2. Instrumentation and Procedure

Eight infrared capture cameras (model T10) of motion capture system (Vicon Inc., Oxford, England) operating at a 100 Hz sampling rate while the participants walked along a 6 m walkway was used to acquire 3D pelvic kinematic data during gait in two different TA and PFM contraction conditions: maximal voluntarily contraction and without contraction (Fig. 1). A verbal instruction and EMG device were used to elicit maximal contraction of the TA and PFM [11]. The participants were asked to gently pull the lower abdomen below the navel to induce the maximum contraction of TA and PFM without moving the trunk and pelvis while intentionally inhaling and exhaling, and provided feedback through EMG to familiarize themselves with the TA and PFM contraction method during gait time in the 6 m walkway [11,17]. A calibration T-wand (750 mm) was used to calibrate the motion analysis system and to identify the lab x-y-z origin. The captured kinematic data were processed using the Nexus 1.8.5 software program (Vicon Inc., Oxford, England) and produced overall c3d files.

To capture 3D pelvic motion during walking condition, participants were attached 40 reflective markers (14 mm) bilaterally to the participants' rearfoot, midfoot, forefoot, medial and lateral malleoli, femur epicondyles, greater trochanters, and anterior and posterior superior iliac spines [15]. The cluster markers were attached both thigh and shank segments according to the six-degrees-of-freedom (6DOF) model (Fig. 2) [18]. First, static calibration data were captured from each participant to create the hybrid model for later analysis of the 3D pelvic motion during gait trials. Participants were asked to walk freely along the 6 m walkway with different TA and PFM activation conditions while we obtained kinematic data of the pelvic segment the Calibrated

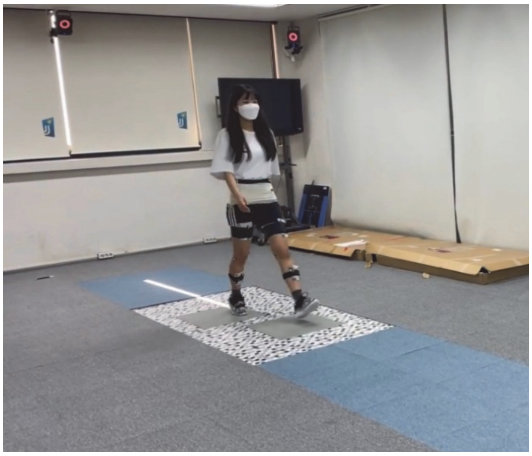

Fig. 1. Eight infrared cameras of three-dimensional motion capture system to acquire 3D pelvic kinematic data during gait.

Fig. 2. Retroreflective and four-cluster markers set to obtain 3D pelvic kinematic data during dynamic walking condition.

Anatomical System Technique after static calibration capture. Participants performed a total of 8 to 10 walk trials per TA and PFM activation condition. Between sets of data collection, the participants were allowed to rest for 3 min to avoid becoming fatigued during the tests. The order in which the muscle contraction conditions was randomly assigned before the gait trials began.

Following the analogue kinematic data acquisition and processing using the Vicon Nexus software program, the Visual3D professional software (Visual3D Pro, C-Motion Inc, USA) was used to acquire the final 3D pelvic motions and graphical reports of the pelvic orientation. Kinematic data were low-pass filtered with a 4th order Butterworth filter and a cutoff frequency of 6 Hz. The X-Y-Z Cardan sequence defined the order of rotations, following the right-hand rule for the segment coordinate system axes [18]. Visual3D created a virtual bone segments model in space based on a set of anatomical reflective markers that enabled the related joint angles to be calculated (Fig. 3).

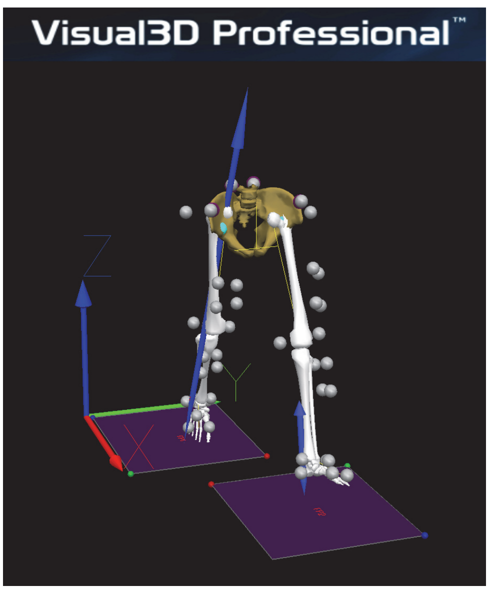

Fig. 3. Visual3D professional used to measure the range of motion of pelvic orientation in 3D space during gait.

3. Data Analysis

The Kolmogorov-Smirnov test was used to confirm that the kinematic pelvic data were distributed normally for parametric testing. Repeated-measures analysis of variance (ANOVA) with Bonferroni adjustment was used to compare the kinematic data of the pelvic segment according to both limb sides and contraction conditions. If the main effect (side or condition) was significant, post-hoc testing was used to determine the differences based on the ANOVA results. All analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Differences were considered significant at the $\alpha = .05$ level.

Ⅲ. Results

Means and standard deviations of 3D pelvic maximal motions were shown in Table 2. There were significant differences between with and without contraction of the TA and PFM of the pelvic depression and the total pelvic motion in coronal plane ($p < .05$) (Table 2). However, there were no significant differences in any of the maximal motion of the pelvic segment in sagittal and transverse

Table 2. Mean Values of Pelvic Maximal Motion with and Without Abdominal and Pelvic Flour Muscles Contraction During Walking Trials (N=20)

Pelvic motion (°)	Contraction	Non-contraction	p
Anterior tilting	1.35 ± .94	1.55 ± 1.09	.105
Posterior tilting	1.62 ± .93	1.63 ± .84	.969
Total sagittal motion	3.24 ± 1.13	2.91 ± 1.23	.267
Elevation	5.99 ± 1.91	6.23 ± 2.01	.264
Depression	3.48 ± 1.19	3.95 ± .97	.001*
Total coronal motion	9.47 ± 2.49	10.18 ± 2.50	.008*
Internal rotation	.99 ± .85	1.10 ± 1.26	.555
External rotation	1.49 ± .90	1.97 ± 1.45	.468
Total Transverse motion	2.48 ± 1.40	3.07 ± 2.04	.313

*$p < .05$

Table 3. Comparison of 3D Pelvic Motion by Contraction Conditions and Foot Sides (Repeated Measures ANOVA, N = 20)

Pelvic motion (°)	Level	F	p
Anterior tilting	Conditions	2.091	.105
	Sides	30.066	.000*
	Conditions × sides	.110	.709
Posterior tilting	Conditions	.000	.969
	Sides	48.909	.000*
	Conditions × sides	.0192	.892
Total range in sagittal plane	Conditions	1.314	.267
	Sides	6.860	.017*
	Conditions × sides	1.136	.298
Elevation	Conditions	1.332	.264
	Sides	13.160	.002*
	Conditions × sides	.767	.392
Depression	Conditions	14.544	.001*
	Sides	.039	.852
	Conditions × sides	3.152	.092
Total range in frontal plane	Conditions	8.744	.008*
	Sides	35.856	.000*
	Conditions × sides	.0014	.981
Internal rotation	Conditions	.362	.555
	Sides	.257	.614
	Conditions × sides	.330	.575
External rotation	Conditions	.551	.468
	Sides	.002	.981
	Conditions × sides	.001	.998
Total range in transverse plane	Conditions	1.077	.313
	Sides	.343	.566
	Conditions × sides	.180	.681

*p < .05

motion plane according to the different contraction conditions (with or without) ($p > .05$) (Table 2).

The results of 2 × 2 repeated-measures ANOVA comparing the 3D maximal motion of the pelvic segment during gait with or without maintained contraction of the TA and PFM are shown in Table 3. Significant differences were seen in the maximal motion of pelvic anterior tilting, posterior tilting, elevation, total sagittal, and total frontal motion between both limb sides during gait ($p < .05$) (Table 3). However, there were no interaction effects between contraction conditions and limb sides in any of the pelvic motion values ($p > .05$) (Table 3).

Ⅳ. Discussion

Objective and quantitative kinematic evaluation plays an important role in obtaining successful outcomes for individuals with musculoskeletal disorders such as CLBP [16]. This study assessed the 3D kinematic values of the pelvic segment using a motion analysis system during gait, which is widely allowed as the most reliable and advisable technology in biomechanics.

This study was to investigate the effect of contraction of the TA and PFM in individuals with non-specific CLBP on three-dimensional pelvic motion during gait. To our knowledge, this study was the first to execute an overall analysis of 3D pelvic movement using with and without muscle contraction of the TA and PFM in individuals with CLBP. The results showed that the contraction condition affected pelvic kinematics during gait compared to the non-contraction condition. This study showed that greater motion changes in the pelvic depression at the beginning of the stance and total range of coronal plane motion occurred in the non-contraction of the TA and PFM condition compared to the contraction condition. These results suggest that contraction maintenance training for the abdominal and PFM can contribute to pelvic stabilization by minimizing up-and-down movements of the pelvic segment during gait. On the other hand, it was found that maintaining the TA and PFM contraction had no significant effect on pelvic rotation and anteroposterior tilting movement during walking. Although these results cannot be directly compared to the reports of previous studies, the elevation and depression movement occurring in the coronal plane of the pelvis showed greater mobility by 10-15 degrees compared to the movement of the pelvis occurring in other movement planes during gait with normal walking velocity [19]. However, the anterior and posterior tilting and rotational movements of the pelvis showed relatively small range of 2-4 degrees [19]. Therefore, it is considered that the intervention of this study had an effect on the kinematic variables of the pelvic segment that caused a larger pelvic motion during gait. Lee et al. [17] verified the movement angle of the pelvis according to abdominal co-contraction exercise through the straight leg raising test. It was reported that the pelvic motion was significantly decreased in the group that received trunk stabilization training through abdominal co-contraction exercise compared to the control group [17].

Patients with CLBP have reduced pelvic stability compared to healthy individuals due to weakness and imbalance of abdominal and PFM, and decreased ability of proprioceptive re-positioning function of the pelvic segment [20,21]. In particular, it is known that the pelvis is the control point that most effectively affects gait ability, and if pelvic stability is decreased, it has a negative effect on gait as well [21]. The PFMs block the outside of the pelvis and support the structures inside the abdominal pelvic cavity [5]. Therefore, maintenance of pelvic stability during gait should be considered as a clinical intervention to treat CLBP and prevent back pain recurrence. In previous studies, it was reported that contraction of PFM promotes 'abdominal hollowing' and 'abdominal bracing' activities that accompany contraction of deep abdominal muscles [10,11]. In addition, Youn and Kim [22] used verbal instruction as a motor control method for the PFM and TA contractions and had a positive effect on the induction of these muscle contractions. Therefore, the same method was used to induce muscle contraction of TA and PFM and instructed to maintain the contractile force during walking in this study.

The strength of this study lies in verifying the kinematic effects of muscle contraction of the TA and PFM on pelvic segments through objective and reliable evaluation system in individuals with CLBP. However, the study has a few limitations that should be noted. As a result of this study, there were significant differences in most of the pelvic movement variables according to the right and left limbs. The cause of these results is considered to be the difference between both limbs in walking parameters such as step length, walking speed, and ground reaction force according to the dominant and the non-dominant foot. However, we were unable to evaluate the subjects' dominant foot and clinical characteristics that affect gait accordingly. Although this study was conducted on individuals with CLBP, most of the participants were young people in their 20s to 30s, and may not represent CLBP patients in various age group. In addition, this study did not verify the effect of co-contraction of the TA and PFM on clinical symptoms such as back pain. Therefore, future studies are needed to verify the relationship between pelvic stability in a various age group of CLBP patients under various therapeutic interventions through objective and quantitative evaluation.

Ⅴ. Conclusion

This study investigated the effects of maintained co-contraction of the TA and PFM on 3D pelvic motion during gait in 20 individuals with CLBP. The results of this study suggest that co-contraction training of the TA and PFM for CLBP reduced pelvic motion and contributed to preventing excessive pelvic movement during gait. Therefore, in terms of preventing and managing CLBP, more aggressive early evaluation and treatment will be needed in clinical practice.

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