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Intensive Abdominal Drawing-In Maneuver After Unipedal Postural Stability in Nonathletes With Core Instability

Nam G. Lee, MS*; Joshua (Sung) H. You, PhD†; Tae H. Kim, PhD‡; Bong S. Choi, PhD*

*Department of Physical Therapy, College of Health and Welfare, Woosong University, Dong-gu, Daejeon, South Korea; †Department of Physical Therapy, Graduate School of Rehabilitation Science, Yonsei University, Wonju City, Gangwon-do, South Korea ‡Department of Physical Therapy, Daegu University, Gyeongsan City, Gyeongsangbuk-do, South Korea

Context: The exact neuromechanical nature and relative contribution of the abdominal drawing-in maneuver (ADIM) to postural instability warrants further investigation in uninjured and injured populations.

Objective: To determine the effects of the ADIM on static core and unipedal postural stability in nonathletes with core instability.

Design: Controlled laboratory study.

Setting: University research laboratory.

Patients or Other Participants: A total of 19 nonathletes (4 women: age = 22.3 ± 1.3 years, height = 164.0 ± 1.7 cm, mass = 56.0 ± 4.6 kg; 15 men: age = 24.6 ± 2.8 years, height = 172.6 ± 4.7 cm, mass = 66.8 ± 7.6 kg) with core instability.

Intervention(s): Participants received ADIM training with visual feedback 20 minutes each day for 7 days each week over a 2-week period.

Main Outcome Measures(s): Core instability was determined using a prone formal test and measured by a pressure biofeedback unit. Unipedal postural stability was determined by measuring the center-of-pressure sway and associated changes in the abdominal muscle-thickness ratios. Electromyographic activity was measured concurrently in the external oblique, erector spinae, gluteus medius, vastus medialis oblique, tibialis anterior, and medial gastrocnemius muscles.

Results: All participants initially were unable to complete the formal test. However, after the 2-week ADIM training period, all participants were able to reduce the pressure biofeedback unit by a range of 4 to 10 mm Hg from an initial 70 mm Hg and maintain it at 60 to 66 mm Hg with minimal activation of the external oblique ($t_{18} = 3.691$, $P = .002$) and erector spinae ($t_{18} = 2.823$, $P = .01$) muscles. Monitoring of the pressure biofeedback unit and other muscle activations confirmed that the correct muscle contraction defining the ADIM was accomplished. This core stabilization was well maintained in the unipedal-stance position, as evidenced by a decrease in the center-of-pressure sway measures (t_{18} range, 3.953–5.775, $P < .001$), an increased muscle-thickness ratio for the transverse abdominis ($t_{18} = -2.327$, $P = .03$), and a reduction in external oblique muscle activity ($t_{18} = 3.172$, $P = .005$).

Conclusions: We provide the first evidence to highlight the positive effects of ADIM training on core and postural stability in nonathletes with core instability.

Key Words: center of pressure, core stabilization, formal test

Key Points

- Static core stability and unipedal postural stability were enhanced in nonathletes with core instability after abdominal drawing-in maneuver training augmented with rehabilitation ultrasound imaging and electromyographic feedback.
- Abdominal drawing-in maneuver training using rehabilitation ultrasound imaging and electromyography effectively improved morphologic changes in transverse abdominis muscle thickness and the neuromuscular pattern of an overactive superficial external oblique muscle, contributing to static core stability and unipedal postural stability.
- Researchers should further investigate the relationship between dynamic core and unipedal postural stability.

Static core stability is an important foundation for static postural control during sports activities. Core stability involves a coordinated stabilization of the lumbo-pelvic-hip complex via active (elastic muscles) and passive (inert ligaments and capsules) stiffness mechanisms.[1] Unlike passive stiffness, active stiffness is a controllable measure that transforms inherent elastic potential energy under a loading condition into kinetic energy, creating sufficient stability.[1,2] Based on this concept, we operationally defined *static core stability* as the active core stabilization achieved by selective activation of the transverse abdominis (TrA) and internal oblique (IO) muscles with a minimal contraction of the other superficial abdominal muscles during the abdominal drawing-in maneuver (ADIM) in the prone position.[3] However, core instability recently has been identified as a pathomarker for low back pain (LBP).[4,5] In fact, Luoto et al[6] examined static unipedal postural stability in chronic LBP and found increased postural sway as evidenced by greater velocity of center-of-pressure (COP) sway than in normal controls.[6]

Table 1. Demographic and Anthropometric Data (N = 19)

Variable	Value
Age, y	24.1 ± 2.7
Height, cm	170.8 ± 5.7
Mass, kg	64.5 ± 8.6
Lower extremity length, cm	88.0 ± 4.1
Foot length, cm	25.0 ± 1.4
Foot width, cm	10.0 ± 0.9
Dominant lower extremity	
Left	8
Right	11
Foot cutaneous proprioception, mm[a]	<22.2
Vestibular test[b]	Normal
Manual muscle test, lb (kg)[c]	
External oblique	18.5 ± 10 (8.33 ± 4.5)
Erector spinae	16.3 ± 9.8 (7.34 ± 4.41)
Gluteus medius	20.9 ± 9.6 (9.41 ± 4.32)
Vastus medialis	26.2 ± 13.9 (11.79 ± 6.26)
Tibialis anterior	19.5 ± 8.8 (8.78 ± 3.96)
Medial gastrocnemius	14.3 ± 4.5 (6.44 ± 2.03)

[a] Foot cutaneous proprioception was determined by 2-point discrimination.[24]

[b] Vestibular function was determined by the Dix-Hallpike maneuver.[25]

[c] Manual muscle test results were determined by the handheld dynamometer according to the Daniels and Worthingham procedure.[26]

Such excessive postural sway could indicate altered core stability and may be related to the causes of some types of LBP.[5] Similarly, Kaji et al[7] evaluated the immediate effect of core-stabilization exercise on static bipedal postural sway in 17 healthy young adults and showed a reduction in the COP sway area and velocity in the mediolateral direction. Muthukrishnan et al[8] compared the differential effects of core-stabilization exercise (static and dynamic) and conventional physiotherapy (mobilization, manipulation, traction, interferential therapy, hyperextension exercise, isometric trunk lifts, pelvic tilts, and basic strengthening exercises) on bipedal postural stability in individuals with LBP and compared their stability measures with those of normal controls. Whereas the core-stabilization exercise resulted in improved postural stability, the conventional physiotherapy did not reveal any meaningful changes, suggesting the important role of the former.

The ADIM has been commonly prescribed because clinical evidence has shown that it effectively manages core instability and associated LBP.[9–16] It is a form of static core-stabilization exercise that involves selective neuromuscular recruitment control of the TrA and IO muscles together with minimal contractions of the other superficial external oblique (EO) and erector spinae (ES) muscles[9,10,13,16] in a variety of positions, such as supine, sitting, sit to stand, standing, and single-limb standing.[17] When the ADIM is performed, the individual isometrically contracts the abdominal wall toward the spine while concurrently compressing the internal organs upward into the diaphragm and downward into the pelvic floor.[13,18] The synergistic activation of the TrA muscle and posterior fibers of the IO muscle increases the tension of the thoracolumbar fascia and generates intra-abdominal pressure, which transforms the abdomen into a mechanically rigid cylinder, thereby increasing lumbar stability.[9,16,19–21] Specifically, the thoracolumbar fascia connects to the contralateral gluteal and hamstrings muscles via the sacrotuberous ligament.[22] Concurrent with the coactivation of the contralateral gluteus maximus muscle, the ADIM increases the stability of the lumbo-pelvic-hip complex,[23] providing overall unipedal postural stability.

Despite the important contribution of core stabilization to postural stability, the effects of ADIM-contributed core stabilization and its underlying mechanisms remain unknown. Hence, an investigation that clarifies the effect of the ADIM on the static postural-control mechanism could provide clinical evidence for effectively managing injured athletes with core instability associated with balance dysfunction. Therefore, the purpose of our study was to determine the effects of the ADIM on static core stability and unipedal postural stability in nonathletes with core instability. Our basic hypothesis was that ADIM training guided by rehabilitation ultrasound imaging (RUSI) would increase static core stability and unipedal postural stability as determined by abdominal muscle thickness, COP sway, and motor-control patterns in nonathletes with core instability.

METHODS

Participants

A convenience sample of 19 nonathletes with core instability (4 women: age = 22.3 ± 1.3 years, height = 164.0 ± 1.7 cm, mass = 56.0 ± 4.6 kg; 15 men: age = 24.6 ± 2.8 years, height = 172.6 ± 4.7 cm, mass = 66.8 ± 7.6 kg) participated in this study (Table 1). The sample size was estimated based on a power of 80% at large differences (0.8) in effect size between the tests. Participants who were unable to successfully perform the formal test 3 consecutive times at baseline were included. However, participants were excluded if they had any neurologic or musculoskeletal impairment that could affect performance during the experimental tests. Initially, we recruited 20 participants, but we excluded 1 participant at the pretest because he did not meet the criterion of core instability, which was manifested in the formal test. All participants provided written informed consent, and the experimental protocol was approved by the Yonsei University College of Health Science Human Studies Committee.

Formal Test

A formal test was used to determine the participants' core stability in the prone position. The ADIM-contributed core-stabilization practice required the participants to lie in a prone position. A pressure biofeedback unit (PBU; Chattanooga Group Inc, Hixson, TN) was placed under the lower abdomen with the lower edge in line with the anterior-superior iliac spine and inflated to 70 mm Hg (Figure 1).[18,27,28] According to the ADIM technique used by Richardson et al,[15,18] each participant was instructed to draw in the lower abdomen below the navel gently and gradually, without moving the upper abdomen, while maintaining a neutral pelvic position. The formal test was considered *successful* when the participant met the following criteria: (1) performed the ADIM while reducing the pressure by approximately 4 to 10 mm Hg and maintaining the target pressure level monitored in the

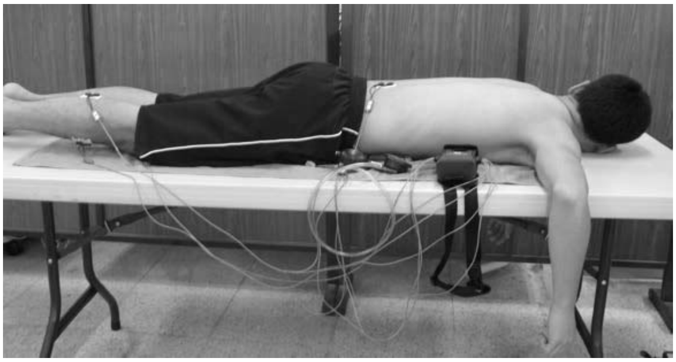

Figure 1. Formal test.

PBU (Figure 2)[18,27,28] and (2) performed the ADIM without substitutions, such as excessive contraction of the EO and ES muscles ($<$15% reference voluntary contraction [RVC]),[15] as evidenced by electromyography or any evasive movements (ie, pelvic rotation, lumbar arching, shoulder elevation, or upper chest expansion).[13] If a participant met only 1 of these criteria, the test was defined operationally as a *failure* or *core instability*. This definition was derived conceptually from previous studies.[13,15,18,27,28]

Experimental Procedures

All participants underwent a pretest followed by intensive ADIM training and a posttest after training. The pretest and posttest measurements included changes in unipedal postural-stability test with the ADIM using RUSI, electromyography, and Matscan (Tekscan Inc, Boston, MA) COP measurements. The dominant foot was determined through the implementation of the single-legged–stance balance test, whereby the participant was instructed to maintain balance as stably as possible, and the more stable side was considered *dominant*.[29] To perform the unipedal postural-stability test, the participant stood on the dominant foot with the upper extremities across the chest and eyes closed for 10 seconds while maintaining equilibrium as stably as possible. The trial was repeated if the participant used the free lower extremity to touch either the ground or the stance extremity or if the upper extremities came off the chest. Participants initially performed 3 practice trials followed by 5 consecutive test trials, which were used for data analysis.

Rehabilitation Ultrasound Imaging Measurement

A real-time brightness-mode ultrasound apparatus (model SonoAce X8; Medison Inc, Seoul, South Korea) was used to assess changes in abdominal muscle (TrA, IO, and EO) thickness and to provide visual biofeedback about muscle contraction. We used a 4.5-cm linear transducer (Medison Inc) with a frequency of 10 MHz.[18] Participants were instructed to lie prone. The examiner palpated the inferior borders of the rib cage and iliac crest to provide anatomic reference points for the abdominal muscles. Ultrasound gel (Aquasonic 100; Parker Inc, Orange, NJ) then was applied to the transducer head, which was placed in a transverse orientation on the anterolateral aspect of the abdomen halfway between the iliac crest and the inferior border of the rib cage (12th rib).[30,31] The angle was manipulated until the sharpest possible images of all abdominal muscles were obtained.[32] All images were captured and stored immediately at the end of the expiration phase, and muscle thickness was determined with an onscreen caliper by 1 investigator (N.G.L.). A vertical reference line positioned 1 cm from the myofascial junction of the TrA muscle was used to measure the TrA, IO, and EO muscle thicknesses (Figure 2).[31] The *myofascial boundaries* were defined as the target layers of the hypoechoic area where the heterogeneous boundaries were manifested in contrasting pixels from dark to light.[32,33] We calculated the contraction ratios of each abdominal muscle and the TrA preferential contraction ratio to identify changes in the relative muscle thicknesses compared with the relaxed state using the following equations: (1) contraction ratio of each abdominal muscle (TrA, IO, and EO) $=$ abdominal muscle contracted/relaxed, and (2) TrA preferential contraction ratio $=$ (TrA contracted/[TrA $+$ IO $+$ EO contracted]) $-$ (TrA relaxed/[TrA $+$ IO $+$ EO relaxed]).[32] The pretest scanning location was marked on a transparent sheet to ensure identical placement throughout the experiment and in the posttest. The anatomic reference locations for the iliac crest and 12th rib were palpated to identify and mark their locations with a permanent marker. Next, we superimposed the transparent sheet over these locations and made corresponding markings on it with the permanent marker.

Electromyography Measurement

We used a TeleMyo 2000 EMG system (Noraxon USA, Inc, Scottsdale, AZ) to record the mean values for the EO,

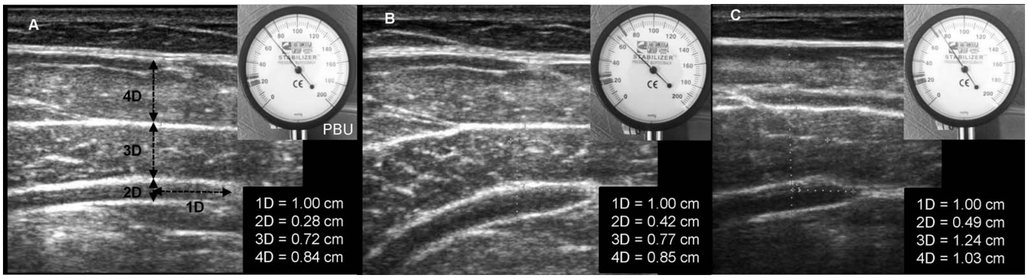

Figure 2. Muscle-thickness analysis. A, Muscle thickness in the relaxed condition. The pressure biofeedback unit (PBU) started at 70 mm Hg. B, Muscle thickness during correct performance of the abdominal drawing-in maneuver. The PBU measurement was reduced and maintained at the target pressure of 64 mm Hg. C, Muscle thickness during incorrect performance of the abdominal drawing-in maneuver. The PBU measurement increased to 75 mm Hg, and external oblique muscle thickness increased. Abbreviations: 1D, reference line; 2D, transverse abdominal muscle; 3D, internal oblique muscle; 4D, external oblique muscle.

Table 2. Formulae for Center-of-Pressure Calculation

COP_{AP} and COP_{ML} sway velocities

$$COP_{AP}vel = \frac{\sum_{t=1}^{T}\left|\frac{xCOP,t - xCOP,t-1}{\Delta t}\right|}{T-1}$$

$$COP_{ML}vel = \frac{\sum_{t=1}^{T}\left|\frac{yCOP,t - yCOP,t-1}{\Delta t}\right|}{T-1}$$

COP_{AP} and COP_{ML} SDs

$$COP_{AP}SD = \sqrt{\frac{\sum_{n=1}^{N}\sum_{t=0}^{T} Sway^2AP,t,n - \frac{\left(\sum_{n=1}^{N}\sum_{t=0}^{T} SwayAP,t,n\right)^2}{N(T-1)}}{NT-1}}$$

$$Sway_{AP} = \frac{\sum_{t=0}^{T}\left|COP_{AP},t - COP_{AP},mean\right|}{T}$$

$$COP_{ML}SD = \sqrt{\frac{\sum_{n=1}^{N}\sum_{t=0}^{T} Sway^2ML,t,n - \frac{\left(\sum_{n=1}^{N}\sum_{t=0}^{T} SwayML,t,n\right)^2}{N(T-1)}}{NT-1}}$$

$$Sway_{ML} = \frac{\sum_{t=0}^{T}\left|COP_{ML},t - COP_{ML},mean\right|}{T}$$

COP sway area

$$COP_{area} = \frac{\begin{gathered}(Sway\,max,ant + Sway\,max,post)\\ \times(Sway\,max,med + Sway\,max,lat)\end{gathered}}{T}$$

$$Sway\,max = \frac{\sum_{t=0}^{T}\left|COPD,t - COPD,mean\right|}{T}$$

Abbreviations: ant, anterior; AP, anteroposterior; COP_{AP}, anteroposterior center of pressure; COP_{ML}, mediolateral center of pressure; COPD, center of pressure in anteroposterior and mediolateral directions; lat, lateral; max, maximum; med, medial; N, number of trials; n, 1 ~ N; post, posterior; T, number of data points per trial; t, a given time point; vel, velocity; xCOP, COP_{AP} data; yCOP, COP_{ML} data.

ES, gluteus medius, vastus medialis oblique, tibialis anterior, and medial gastrocnemius muscles.[34,35] These electromyographic data were used to ensure proper muscle activation and provide visual feedback during the ADIM training. The skin was prepared carefully to reduce skin impedance to less than 5 kΩ by dry shaving hair with a disposable razor and cleansing the skin with a 2% alcohol swab. When the skin was dry, we placed pregelled bipolar Ag/AgCl disposable electrodes (Bio-Protech Inc, Wonju, South Korea) with a contact length and width of 36 × 23 mm over the EO, ES, gluteus medius, vastus medialis oblique, tibialis anterior, and medial gastrocnemius muscle bellies[36] on the side of the body with the weight-bearing limb during the unipedal postural stability test at an interelectrode distance of 2.0 cm. A reference electrode was positioned over the anterior-superior iliac spine. Two representative peak electromyographic amplitude values out of the 5 trials were obtained at the maximal expiratory volume during the unipedal stance position by monitoring with a spirometer (TECKSCIENCE Inc, Seoul, South Korea),[15] and the middle 0.35-second electromyographic signals were averaged to provide a stable reference value. We used this reference anchor to calculate the percentage of the RVC for normalization of the aforementioned muscles. The raw electromyographic signal data were recorded at a sampling frequency of 1500 Hz and processed with a 60-Hz notch filter using MyoResearch software (version 1.06; Noraxon USA, Inc, Scottsdale, AZ) to reduce the noise associated with electrical interference, including 60-Hz power lines or radio frequencies and electric or magnetic devices. The root mean square electromyographic amplitude for each EO, ES, gluteus medius, vastus medialis oblique, tibialis anterior, and medial gastrocnemius muscle was computed for 10 seconds during the ADIM. The raw electromyographic signal was full-wave rectified and bandpass filtered at 15 to 500 Hz.[37]

Center-of-Pressure Measurement

The center-of-pressure (COP) measurement was used to determine the COP sway measures: anteroposterior COP (COP_{AP}) and mediolateral COP (COP_{ML}) sway velocities (cm/s), COP_{AP} and COP_{ML} standard deviations (SDs; cm), and COP sway areas (cm^2). The COP_{AP} and COP_{ML} sway velocities were the mean values of the instantaneous velocity of the COP in a given direction during a given time. The COP_{AP} and COP_{ML} SDs were the total SDs of the sway during a given time for a given number of trials. The COP sway area represented the maximal anterior, posterior, medial, and lateral sways during a given time.[38] Before data acquisition, automatic calibration was implemented based on each participant's body weight. The COP data were acquired at a sampling rate of 40 Hz for 10 seconds while the participant maintained equilibrium as stably as possible during the unipedal postural-stability test.[39] The raw COP data that we collected were converted to ASCII using F-Scan (version 6.0; Tekscan Inc, Boston, MA) software. We used MATLAB (version R2008A; The MathWorks, Inc, Natick, MA) to compute the COP data using the formulae provided in Table 2.[38]

Intrarater Reliability

Before the intervention, we established the intrarater reliability of the RUSI and Matscan COP measurements by measuring the thickness of the abdominal muscles and COP sway velocity during unipedal stance on 2 occasions approximately 24 hours apart. An ultrasound measurement for test-retest reliability was obtained in the relaxed state (without the ADIM) during the unipedal stance for all participants.

Intervention

We determined the baseline core-stabilization performance of each participant. Next, we introduced the ADIM exercise using the PBU, RUSI, and electromyography in the supine hook-lying, prone, quadruped, and bilateral-stance positions followed by a unipedal stance in progression (Figure 3). According to the ADIM procedures described by Richardson et al,[15,18] each participant was instructed to relax the upper chest and abdomen and to gently and gradually draw in the lower abdomen below the

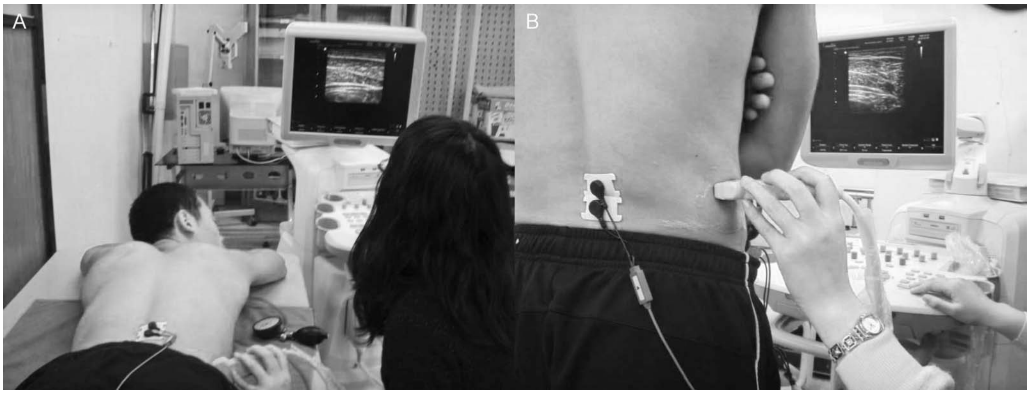

Figure 3. Training procedure. A, B, Augmented abdominal drawing-in maneuver training with a pressure biofeedback unit, rehabilitation ultrasound imaging, and surface electromyography was used to optimize motor control of the transverse abdominal muscle.

navel without moving the upper abdomen or spine while maintaining a neutral pelvic position and exhaling with lateral chest expansion for 10 seconds, which was monitored using a digital watch (Casio Inc, Tokyo, Japan). After each ADIM practice, a 20-second rest interval was provided. This intervention lasted for 20 minutes each day, 7 days each week, over a 2-week period.

Statistical Analysis

The descriptive statistics included means and SDs. We used a paired *t* test to assess the mean differences in the TrA, IO, and EO muscle thicknesses; the electromyographic amplitudes; and the COP sway measures between the pretest and posttest. The intraclass correlation coefficient (ICC [1,2]) was calculated to determine intrarater reliability. Further analysis regarding the power and effect size of the TrA preferential contraction ratio also was conducted. Findings were considered different at $P < .05$. We used the SPSS for Windows software (version 12.0; SPSS Inc, Chicago, IL) for the statistical analysis.

RESULTS

Formal Test

Initially, no participants were unable to complete the formal test, but after 2 weeks of ADIM training, all could successfully reduce the pressure on the biofeedback unit by a range of 4 to 10 mm Hg from 70 mm Hg and maintain it at 60 to 66 mm Hg with minimal EO and ES muscle contraction (<15% RVC) 3 consecutive times. The mean electromyographic amplitudes of the superficial EO ($t_{18} = 3.691$, $P = .002$) and ES ($t_{18} = 2.823$, $P = .01$) muscles were decreased after the intervention, confirming that superficial abdominal-muscle activation was inhibited effectively after ADIM training (Table 3).

Rehabilitation Ultrasound Imaging Data

The TrA contraction ratio in the unipedal-stance position differed between the pretest and posttest ($t_{18} = –2.327$, $P = .03$; Table 4).This finding indicates that the thickness of the TrA muscle was improved after ADIM training with RUSI and electromyographic feedback. The preferential contraction ratio for the TrA muscle tended to increase during the unipedal-stance position in the posttest ($t_{18} = –2.074$, $P = .053$). The power analysis and effect size of the TrA preferential contraction ratio showed relatively moderate power (0.596) and a small effect size (0.231), respectively.

Electromyography Data

A comparison of the normalized electromyographic amplitudes (% RVC) between the pretest and posttest with and without ADIM in the unipedal-stance position is presented in Table 5. Activation of the EO muscle differed between the pretest and posttest ($t_{18} = 3.172$, $P = .005$).

Center-of-Pressure Data

We found differences in the COP_{AP} and COP_{ML} velocities ($t_{18} = 4.720$ and 5.775, respectively) and SDs ($t_{18} = 5.558$ and 3.953, respectively) and in the COP area ($t_{18} = 4.628$) between the pretest and posttest ($P < .001$; Figures 4 through 6).

Intrarater Reliability

Intrarater reliability of the abdominal muscle thickness and COP measures in the unipedal-stance position was determined. An ICC analysis showed high intrarater reliability for the muscle-thickness measure (ICC [1,2] = 0.76–0.98) and COP_{AP} and COP_{ML} sway velocities (ICC [1,2] = 0.96–0.97), suggesting that both the muscle

Table 3. Muscle Activity Data During the Formal Test (Mean ± SD)

Muscle	Pretest, % Reference Voluntary Contraction	Posttest, % Reference Voluntary Contraction	t_{18} Value	*P* Value
External oblique	41.5 ± 32.5	13.3 ± 12.1	3.691	.002[a]
Erector spinae	19.2 ± 20.7	7.1 ± 6.5	2.823	.01[a]

[a] Significant at $P < .05$.

Table 4. Abdominal Muscle Contraction and Transverse Abdominal Muscle Preferential Contraction Ratios During the Unipedal Stance Position (Mean ± SD)

Ratio	Pretest	Posttest	t_{18} Value	*P* Value
Transverse abdominal muscle contraction	1.40 ± 0.31	1.57 ± 0.21	–2.327	.03[a]
Internal oblique muscle contraction	1.14 ± 0.15	1.20 ± 0.19	–0.959	.35
External oblique muscle contraction	1.00 ± 0.10	0.99 ± 0.03	0.121	.91
Transverse abdominal muscle preferential contraction	0.04 ± 0.03	0.06 ± 0.02	–2.074	.053

[a] Significant at $P < .05$.

thickness (Table 6) and COP_{AP} and COP_{ML} sway-velocity measures (Table 7) were consistently reliable.

DISCUSSION

Our study highlights the effects of ADIM training on static core stability and unipedal postural stability in nonathletes with core instability. As anticipated, static core stability and unipedal postural stability were enhanced after ADIM training augmented with RUSI and electromyographic feedback. Given that we present the first evidence in the literature of the important role of core-stability training in unipedal postural stability, comparing our data with those of other studies is difficult.

Most importantly, all of the nonathletes with initial core instability successfully performed a formal core-stability test with substantially decreased excessive EO (from 41.5% to 13.3% RVC) and ES (from 19.2% to 7.1% RVC) muscle activation after the intervention. This core-stabilization–training effect was evident even during the higher hierarchy of the unipedal postural-stability test. Our data are in line with those of previous studies[15,22,40,41] in which the authors examined the effect of the ADIM on lumbopelvic core stability in uninjured participants[22] and participants with LBP. Richardson et al[15] compared the differential effects of abdominal bracing and the ADIM on sacroiliac joint laxity in a healthy population using the Doppler color image of the vibrating (200 Hz) sacrum and ilium and showed a superior effect of the ADIM on sacroiliac laxity or stiffness compared with a control population. The probable reason for such an improvement is that the ADIM activates the deep TrA and IO muscles independent of the superficial EO and ES muscles, stiffening the sacroiliac joint. Drysdale et al[40] examined the normalized peak electromyographic amplitude of the rectus abdominis and EO muscles in healthy young adults and found greater reduction of the global abdominal rectus abdominis and EO muscles during the ADIM than during pelvic tilting, regardless of the testing position. In a recent randomized clinical trial, Chon et al[41] evaluated the augmented effects of combined ADIM and sequential voluntary cocontraction training via resisted ankle dorsiflexion on TrA and IO electromyographic activation patterns, abdominal muscle thickness, and associated pain reduction in patients with LBP. This ADIM, combined with cocontraction, enhanced muscle activity with associated morphologic changes in the TrA and IO muscles, thereby reducing LBP. In this study, an increase in TrA muscle thickness was accompanied by an increase in IO muscle thickness. Certainly, this finding suggests that the ADIM does not activate the TrA muscle independently but rather coactivates it with the IO muscle to optimize static core stability, which is a prerequisite for static postural stability.

We determined unipedal postural stability and associated neuromuscular performance by the COP sway with parallel measurements of RUSI muscle thickness and electromyographic muscle activity during a unipedal stance. The COP sway analysis showed that the COP_{AP} and COP_{ML} sway velocities, SDs, and areas were improved markedly after the ADIM training. This finding corroborates the observations of other recent authors[7,8] who investigated the effect of core-stabilization exercises on bipedal postural stability. Muthukrishnan et al[8] compared the long-term effects of core-stabilization exercise (progression from static to dynamic) and conventional physical therapy in patients with chronic LBP and found improvements in the dynamic postural-stability measures (force, moment, and COP) that were comparable with those of healthy controls. Similarly, Kaji et al[7] evaluated the immediate effects of core stabilization (elbow-toe and hand-heel) exercises on static postural stability in 17 healthy young adults and showed

Table 5. Normalized Electromyographic Amplitudes During the Unipedal Stance Position (Mean ± SD)

Muscle	Condition	Pretest, % Reference Voluntary Contraction	Posttest, % Reference Voluntary Contraction	t_{18} Value	*P* Value
External oblique	Rest	35.0 ± 29.2	22.1 ± 10.2	1.957	.07
	ADIM	56.0 ± 36.2	29.3 ± 13.4	3.172	.005[a]
Erector spinae	Rest	55.7 ± 49.0	53.0 ± 33.5	0.195	.85
	ADIM	73.9 ± 55.7	57.7 ± 29.8	1.085	.29
Gluteus medius	Rest	81.0 ± 103.9	82.1 ± 69.1	–0.038	.97
	ADIM	74.6 ± 83.2	73.4 ± 58.0	0.059	.95
Vastus medialis oblique	Rest	30.8 ± 17.5	37.1 ± 24.2	–1.399	.18
	ADIM	51.4 ± 51.3	47.2 ± 42.8	0.301	.77
Tibialis anterior	Rest	53.4 ± 45.5	80.5 ± 50.3	–1.595	.13
	ADIM	96.3 ± 45.3	67.1 ± 34.8	2.075	.053
Medial gastrocnemius	Rest	120.6 ± 66.9	114.7 ± 59.4	0.303	.77
	ADIM	125.4 ± 57.3	111.6 ± 54.9	0.817	.43

Abbreviation: ADIM, abdominal drawing-in maneuver.

[a] Significant at $P < .05$.

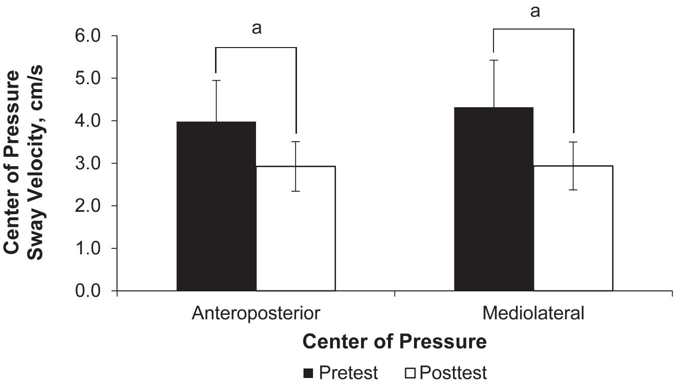

Figure 4. Center-of-pressure sway velocity during the unipedal stance position. [a] $P < .05$.

changes in the maximal ranges and SDs of the COP_{ML} sway and COP_{AP} and COP_{ML} sway velocities.

Our concurrent RUSI and electromyographic data analyses of core and postural muscles during unipedal postural-stability testing revealed that TrA muscle thickness increased, EO muscle activation decreased, and tibialis anterior and ES muscle activity tended to decrease after ADIM biofeedback training. These results suggest that ADIM training helped to stimulate TrA muscle activation while inhibiting superficial EO and ES muscle activation. This efficient neuromuscular control increased lumbopelvic stability, subsequently diminishing or neutralizing the demand of excessive ankle muscle activity. One important mechanism by which the ADIM improved the neuromuscular function of the TrA muscle and associated lumbar spinal stability was the neuromechanical stiffening of the thoracolumbar fascia. The synergistic contraction of the TrA muscle and posterior fibers of the IO muscle increases posterolateral lumbar tension on the thoracolumbar fascia, which connects to the contralateral gluteal and hamstrings muscles via the sacrotuberous ligament. Coactivation of the TrA and IO muscles, together with the thoracolumbar fascia, increases intra-abdominal pressure and creates a more rigid, or stiffer, cylinder of the abdomen. This core stiffness or stability of the lumbar spine results in static unipedal postural stability.[9,16,19–23] Static core stability and unipedal postural stability are important elements for clinical diagnosis, the early phase of sport rehabilitation, and the prevention of recurrent LBP and associated postural instability.

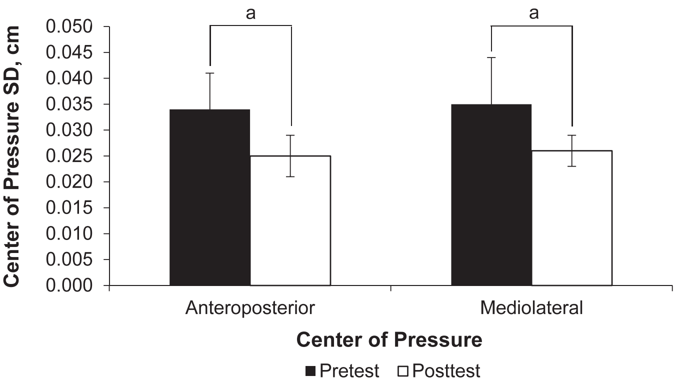

Figure 5. Center-of-pressure SD during the unipedal stance position. [a] $P < .05$.

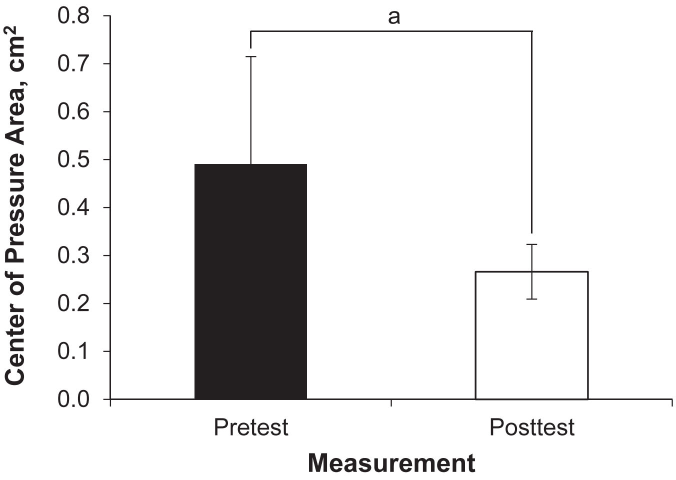

Figure 6. Center-of-pressure sway area during the unipedal stance position. [a] $P < .05$.

Notwithstanding the clinical implications of our novel findings, our study had several shortcomings. First, the neuromuscular-control mechanism of the deep core muscles (ie, TrA, IO, mulitifidus, and quadratus lumborum) during the stability tests was not determined by surface electromyography. However, muscle thickness is an important indicator for neuromuscular control.[42] Second, our primary goal was to examine the ADIM intervention-related effects on unipedal postural stability in nonathletes with core instability rather than just compare the relative changes or effects of the ADIM between the relaxed and contracted (ADIM) conditions during the static unipedal stance. We did not measure static unipedal postural stability (COP measure) in the relaxed state, yet the relative effects of the ADIM on postural stability warrant further evaluation. Third, the preferential contraction ratio of the TrA was different at $P = .053$, indicating that the ratio tended to improve as a function of ADIM training, which was manifested consistently in the TrA muscle-thickness data. Further analysis regarding the power (0.596) and effect size (0.231) of the TrA preferential contraction ratio showed that they were of relatively moderate power and small effect size, which may indicate the need for a larger sample size. Fourth, in our preliminary investigation, we explored the static core stability and unipedal postural-stability mechanism of ADIM training in pain-free individuals with core instability. Our results cannot be generalized to other populations with differential pathologic conditions or dynamic core- and postural-stability conditions.[43] Our findings invite researchers to examine the relationship between dynamic core and unipedal postural stability. Nevertheless, our results make an important contribution to the existing body of knowledge

Table 6. Intrarater Reliability for Measuring Abdominal Muscle Thickness

Muscle	Intraclass Correlation Coefficient [1,2] (95% Confidence Interval)	Standard Error of the Measurement, cm
Transverse abdominal	0.76 (0.40, 0.91)	0.06
Internal oblique	0.84 (0.60, 0.94)	0.17
External oblique	0.98 (0.95, 0.99)	0.07

Table 7. Intrarater Reliability for Measuring Center-of-Pressure Sway Velocity

Center-of-Pressure Direction	Intraclass Correlation Coefficient [1,2] (95% Confidence Interval)
Anteroposterior	0.97 (0.80, 0.99)
Mediolateral	0.96 (0.76, 0.99)

on core-stabilization exercise of the abdominal muscles in populations with core instability.

CONCLUSIONS

We demonstrated that ADIM training using RUSI and electromyography effectively improved morphologic changes in TrA muscle thickness and the neuromuscular pattern of an overactive superficial EO muscle, contributing to static core stability and unipedal postural stability. Our findings may provide clinical insights for sport rehabilitation to improve static core and postural stability in injured athletes with core instability.

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Address correspondence to Joshua (Sung) H. You, PhD, Department of Physical Therapy, Graduate School of Rehabilitation Science, Yonsei University, 234 Maeji-ri, Heungup-myun, Wonju, Gangwon-do, Republic of Korea, 220–710. Address e-mail to neurorehab@yonsei.ac.kr.

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In the February 2015 issue of the *Journal of Athletic Training*, the title of the following article was incorrect:

Lee NG, You JH, Kim TH, Choi BS. Intensive abdominal drawing-in maneuver after unipedal postural stability in nonathletes with core instability. *J Athl Train*. 2015;50(2):147–155.

The correct title is "Unipedal postural stability in nonathletes with core instability after intensive abdominal drawing-in maneuver." We regret the error.