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Activation of Pelvic Floor Muscle During Ankle Posture Change on the Basis of a Three-Dimensional Motion Analysis System

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

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Background: Weak pelvic floor muscles (PFMs) is an important cause of stress urinary incontinence. Effective strengthening of PFMs is very helpful in improving lower urinary tract disease. The purpose of this study was to determine the activation of PFMs in accordance with movement of the pelvis and ankle.





Material/Methods: Fifty healthy adults who underwent PFM contraction in ankle posture change (dorsiflexion, neutral, and plantar flexion) while standing were simultaneously measured using electromyography and motion capture systems. Muscle activity at the tibialis anterior and gastrocnemius muscles was measured by surface electromyography electrodes and PFMs was measured using anal/vaginal probe. Motion analysis was captured by 3-dimensional motion trajectories of the retro-reflective markers.

Results: At the ankle dorsiflexion, pelvic tilted anteriorly and PFMs were activated, but there was no pelvic movement in ankle plantar flexion. Significantly greater PFM activities were seen in ankle dorsiflexion.

Conclusions: PFM exercises performed in active ankle dorsiflexion positions while standing may increase the effectiveness of these exercises. For an effective pelvic floor enhancement in patients with weak PFMs, we recommend a dorsiflexion of the ankle in the standing position.

MeSH Keywords: **Ankle • Electromyography • Pelvic Floor • Posture**

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Background

As life expectancy increases, health has become an essential for enjoying a quality life [1]. Urinary incontinence, which has a high prevalence rate in middle-aged women, may not be discussed openly because of embarrassment. However, there is a growing awareness of urinary incontinence as a critical factor that influences quality of life [2].

Stress incontinence is a type of urinary incontinence which is a result of increased abdominal pressure, whereas urge incontinence is due to detrusor instability, and mixed incontinence is a combination of the stress and urge incontinence [3,4]. Stress urinary incontinence (SUI) is the more common of these condition, in which involuntary leakage occurs when abdominal pressure is increased by effort, exercise, sneezing, or coughing [3].

SUI occurs more frequently in women than in men, and is responsible for approximately 30% of the cases of urinary incontinence in women [5,6]. This is due to relaxation of the pelvic floor muscles (PFMs) due to pregnancy and childbirth, as well as the anatomical differences in the urogenital system between men and women [5,7]. Weakening of the connective tissue structure of the pelvic floor and loosening of the pelvis can lead to SUI [7].

In patients with SUI, muscle re-education and exercise are essential to improve strength and function of the PFMs [8]. There have been multiple studies on the effects of PFM exercises, however, often other adjacent muscles are unnecessarily used to compensate for the function of PFMs [9–11]. Exercises in appropriate postures that lead to selective muscle contractions in the PFMs may be more effective. Therefore, it is important to confirm that the changes in activation of PFMs are in accordance with changes in posture [12–14]. Studies involving pelvic tilt and activation of PFMs while standing have shown greater activation of PFMs with posterior pelvic tilting compared to anterior pelvic tilting or neutral positions [12,14,15]. Depending on the ankle posture, the pelvic tilt can change [12,14,15].

Previous studies reported that the height of the heel caused an angle change in the pelvic tilt, and that pelvic muscles were activated upon ankle dorsiflexion [15]. Previous studies have also compared the activation of PFMs at fixed ankle positions [14,16].

The pelvic angle is fixed according to the ankle position, and the pelvic posture is defined [12,14,16], however, there is unclear and there is insufficient explanation about the specific relationship between the ankle and the pelvic posture. Former research simply has recommended avoiding high heels and wearing flat shoes to prevent urinary incontinence. There has not been research on optimal ankle positioning during PFM training for maximum PFM activation. It will thus be helpful to establish and improve PFM training principles if we understand PFM activation by ankle position strategy.

Electromyography (EMG) is a non-invasive method used to assess the degree of muscle weakness, is used as an indirect indicator of muscle neural innervation patterns, and is commonly used for PFM measurement as well as for PFM training. This study aimed to confirm that the activation of the PFMs is in accordance with movement of the pelvis and ankle, by real-time simultaneous analysis using motion analysis and EMG.

Material and Methods

Patients

We selected 50 healthy adults (24 men and 26 women) aged 28–49 years. Exclusion criteria were pregnancy, menstruation, musculoskeletal or neurological abnormalities such as sensory abnormalities or muscle paralysis, mental problems, and inability to perform exercises due to lack of understanding.

Ethical approval was provided by The University of Sahmyook Human Research Ethics Committee, and all participants were provided verbal and written explanation of study procedures

Table 1. General characteristics of patients.

	Male n=24	Female n=26	Total N=50
Age (year)	41.08±5.27	35.69±4.63	38.28±5.60
Height (cm)	174.16±2.80	162.49±4.85	168.09±7.10
Weight (kg)	72.45±4.45	53.61±3.62	62.66±10.31
BMI (kg/m ²)	23.90±1.62	20.30±0.94	22.03±2.23
Childbirth (yes/no)		11/15	

Values are presented as n (%) or mean ± standard deviation. BMI – body mass index.

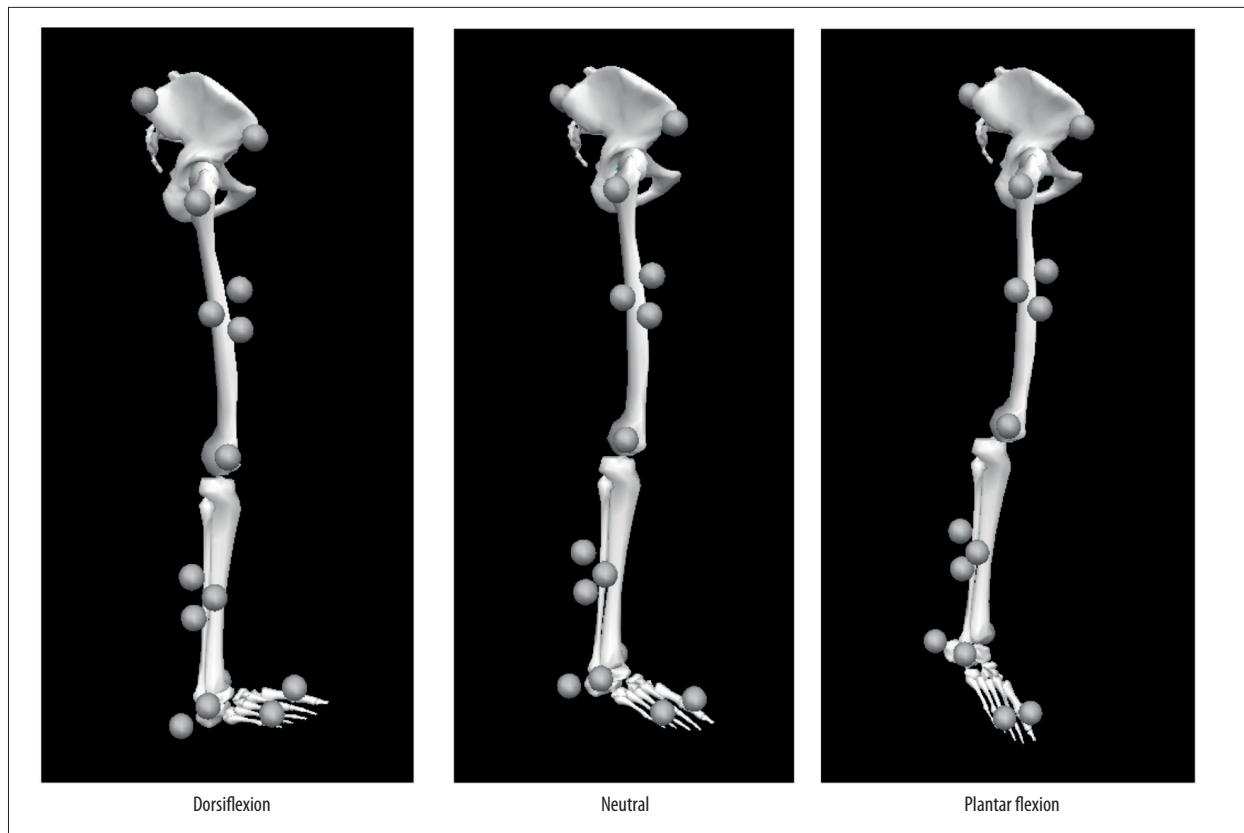


Figure 1. Ankle and pelvic posture.

and signed an informed consent forms prior to participation. The general characteristics of the patients are shown in Table 1.

Procedure

Testing was performed in a private room allocated for this study. EMG and motion data were collected during each patient's ankle posture change (dorsiflexion, neutral, and plantar flexion of the ankle joint) (Figure 1). The patients were kept in a straight posture so that no flexion or extension of the trunk was observed in all test positions and unnecessary pelvic movement was avoided. The patients were allowed only natural pelvic movement due to ankle dorsiflexion. Five measurements were performed for each posture, and the order of measurements was randomized.

Before the experiment, all patients were educated in PFM contractions to assess PFM activation. Prior to measurement, an anal or vaginal probe was inserted and secured with medical tape; and enough time was allocated to accommodate the probe. To confirm that the probe was properly inserted into the anus/vagina, we checked using computerized feedback, with the circle diameter changing as the anus/vagina contracted. After sufficient visual feedback training, the pelvic contraction method was verified, and measurement was

initiated. Measurement was performed 5 times and involved 5-second contraction of PFMs and 10-second of relaxation. All data were used as the average of 5 repeated evaluations. The measurement protocol was based on research methodology of previous studies on PFMs, modified to meet the purpose of this study [17].

Measurements

Muscle activity was measured using EMG (TELEMYO 24000 TG2, Noraxon Inc., USA). The activation of the PFMs was measured using an anal/vaginal probe electrode (EMG A/STIM channel of the Pathway, The Prometheus Group, USA), which was inserted in the anus or vagina and attached to the PFMs. The reference and measuring electrodes were arranged at a predetermined interval on the probe electrode. At the probe end, a large part remained in contact with the inner wall of the anus or the vagina. Before measurement, the patient looked at the computer monitor and contracted or relaxed the vagina/anus according to the instructions of the examiner. In addition, 2 pairs of electrodes (1 cm in diameter, 3 cm center-to-center distance) were placed on the tibialis anterior and gastrocnemius (lateral head) muscles respectively, to monitor the activities of these muscles. All electrodes were secured with a hypoallergenic adhesive tape to reduce any movement artifacts.

Signals from the electrodes were acquired via EMG and stored in a computer via software (Myoresearch XP Master Edition, Noraxon Inc., USA). The EMG signal was processed by a low pass filter of 60 Hz, using a bandpass filter of 10 Hz to 250 Hz to remove noise, and a root mean square (RMS) value was calculated. EMG data was collected at 1200 Hz, whereas video data was captured at 60 fields/sec.

To normalize the EMG value, maximal voluntary isometric contraction (MVIC) was measured for 5 seconds per muscle at the manual muscle test position. The measured value was converted to root mean square, and the average signal amount for 3 seconds except the first and last 1 second was defined as 100% MVIC. The measurement was repeated 3 times and there was a 1-minute break between measurements.

A 250-Hz 8-camera Qualisys motion capture system (Miquis M3 series, Qualisys AB, Sweden) was used in an indoor motion analysis facility to capture 3-dimensional motion trajectories of the retro-reflective markers (10 mm in diameter) placed on the participant's body. A total of 34 retro-reflective markers were used to model the body as a system of rigid segments. Markers were placed over anterior superior iliac spines (2), posterior superior iliac spines (2), sacrum (1), greater trochanters (2), lateral thighs (6), lateral epicondyles (2), medial epicondyles (2), lateral shanks (3), lateral malleoli (2), medial malleoli (2), heels (2), 2nd toes (2), and 5th toes (2).

Visual3D motion analysis software (C-Motion, Germantown, USA) was used for further processing and analysis of the data. A zero lag 4th-order Butterworth low-pass filter with a cut-off frequency of 6 Hz was used for data reduction. The x-, y-, and z-axis of the segmental frames were aligned with the mediolateral, anteroposterior, and longitudinal axes of the segments, respectively. Participant's body was modeled as a system of 4 linked segments: pelvis, thighs, shanks, and feet. The kinematic parameters measured using the camera were analyzed using Visual3D.

Statistical analysis

Descriptive statistics were used for general characteristics of the patients. A one-way repeated measures ANOVA was used to explore muscle activation changes according to posture, and a Scheffe test was performed for post-hoc analysis. SPSS version 19.0 on Windows was used to perform all analyses and *P* values <0.05 were regarded as significant.

Results

Figures 2 and 3 show the activation of each muscle simultaneously with ankle and pelvic angle changes. Figure 2 shows the

activity of each muscle during dorsiflexion of the ankle. Tibialis anterior showed high activity and gastrocnemius showed low activity. In the ankle dorsiflexion, the pelvis tilted forward, and PFM was activated.

Figure 3 shows the activity of each muscle during ankle plantar flexion. gastrocnemius showed marked activation and tibialis anterior also showed activation, indicating co-contraction of dorsiflexor and plantar flexor.

Table 2 shows the mean and standard deviation of maximal muscle voluntary isometric contraction (MVIC%) with ankle motion. Anal pelvic floor muscle showed the highest activity on dorsiflexion: 11.96% on neutral, 22.86% on plantar flexion, and 43.67% on dorsiflexion. Post-hoc test results showed statistically significant difference (*P*<0.05). The same result was obtained in the comparison of each sex. Vaginal pelvic floor muscle showed the highest activity on dorsiflexion: 17.44% on neutral, 23.37% on plantar flexion, and 37.54% on dorsiflexion. Post-hoc test results were statistically significant difference (*P*<0.05). Tibialis anterior showed the highest activity in dorsiflexion (77.46%) and gastrocnemius showed the highest activity in plantar flexion (55.78%), and post-hoc test showed statistically significant difference (*P*<0.05).

Discussion

PFM exercises are essential for prevention of SUI and treatment of patients with SUI [8]. However, it is difficult to standardize effective exercise methods [18]. Exercising in an effective posture to activate the PFMs can maximize results.

It is important to identify the optimal exercise posture to activate the PFMs. There were no studies that simultaneously analyzed the effect of pelvic and ankle position on PFM activity. In this study, the effects of pelvic and ankle movements on the activation of pelvic muscles were analyzed simultaneously in real time through motion analysis and EMG.

We showed that ankle dorsiflexion was the more appropriate posture compared to neutral or ankle plantar flexion to activate PFMs. Motion analysis confirmed that the pelvis tilts anteriorly on ankle dorsiflexion, and the PFMs are activated. In the standing posture with ankle dorsiflexion, the activity of anal PFMs increased to 14.47 MVIC% in males and 27.62 MVIC% in females, and 20.10 MVIC% in vaginal PFMs. The results of this study were consistent with the results of a previous study [19] that stating that PFMs were activated due to stretching by posterior rotation of the coccyx during anterior tilting of the pelvis.

The pelvis tilts anteriorly and the position of the sacrum opens the pelvic outlet, and both ischial tuberosities move away from

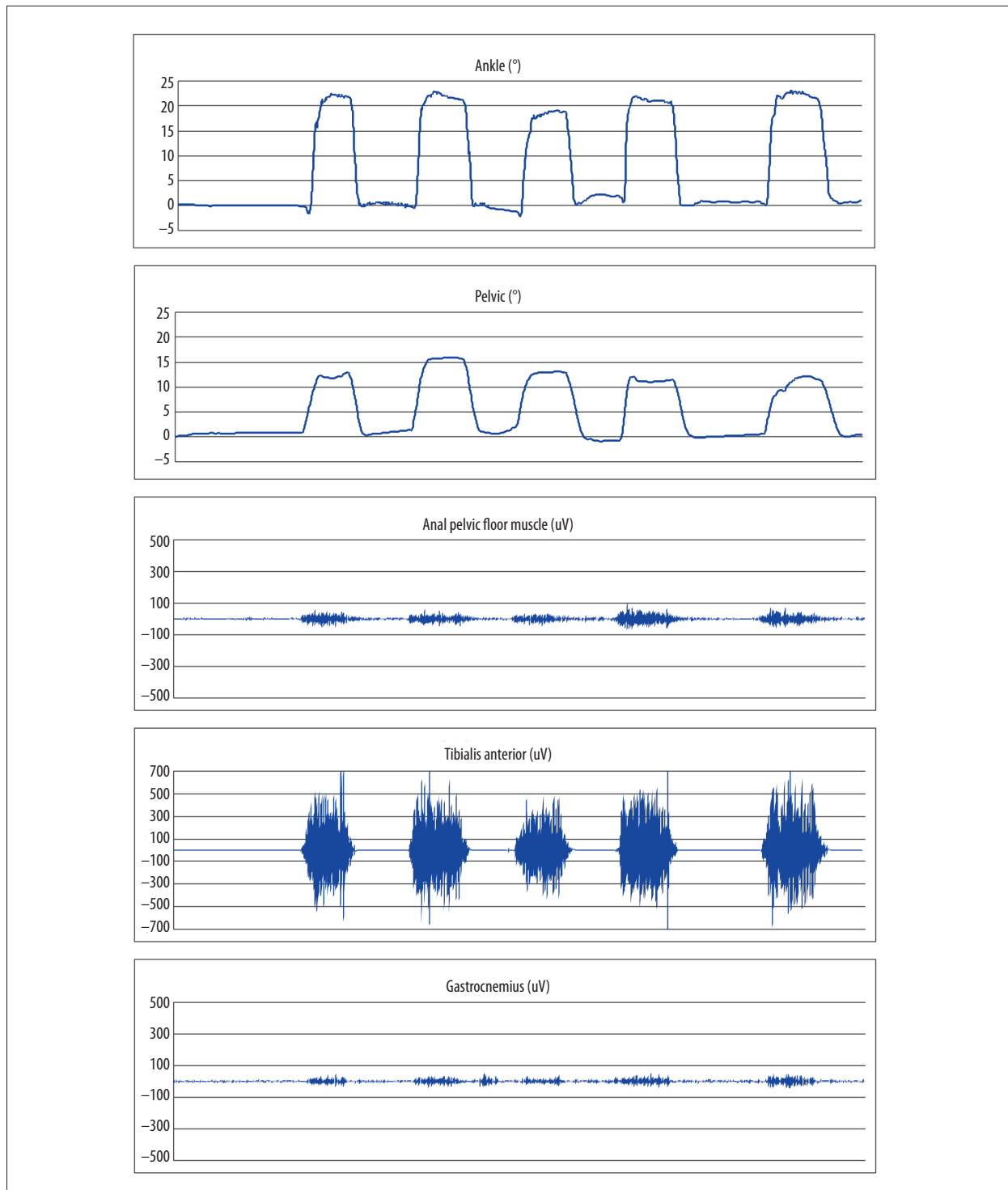


Figure 2. Ankle and pelvic angle and muscle activity in ankle dorsiflexion.

each other, causing the PFM to tighten [20]. Although ankle dorsiflexion is not directly related to the pelvic floor, it is thought to induce pelvic anterior tilting and increase the activation of the PFM [12,14,15].

As per previous studies, the pelvis tilts posteriorly and coccyx moves anteriorly during ankle plantar flexion in the standing posture, leading to the shortening of muscle fibers [12,19]. However, no pelvic movement occurred at the time of ankle plantar flexion. Although there was no pelvic movement, pelvic

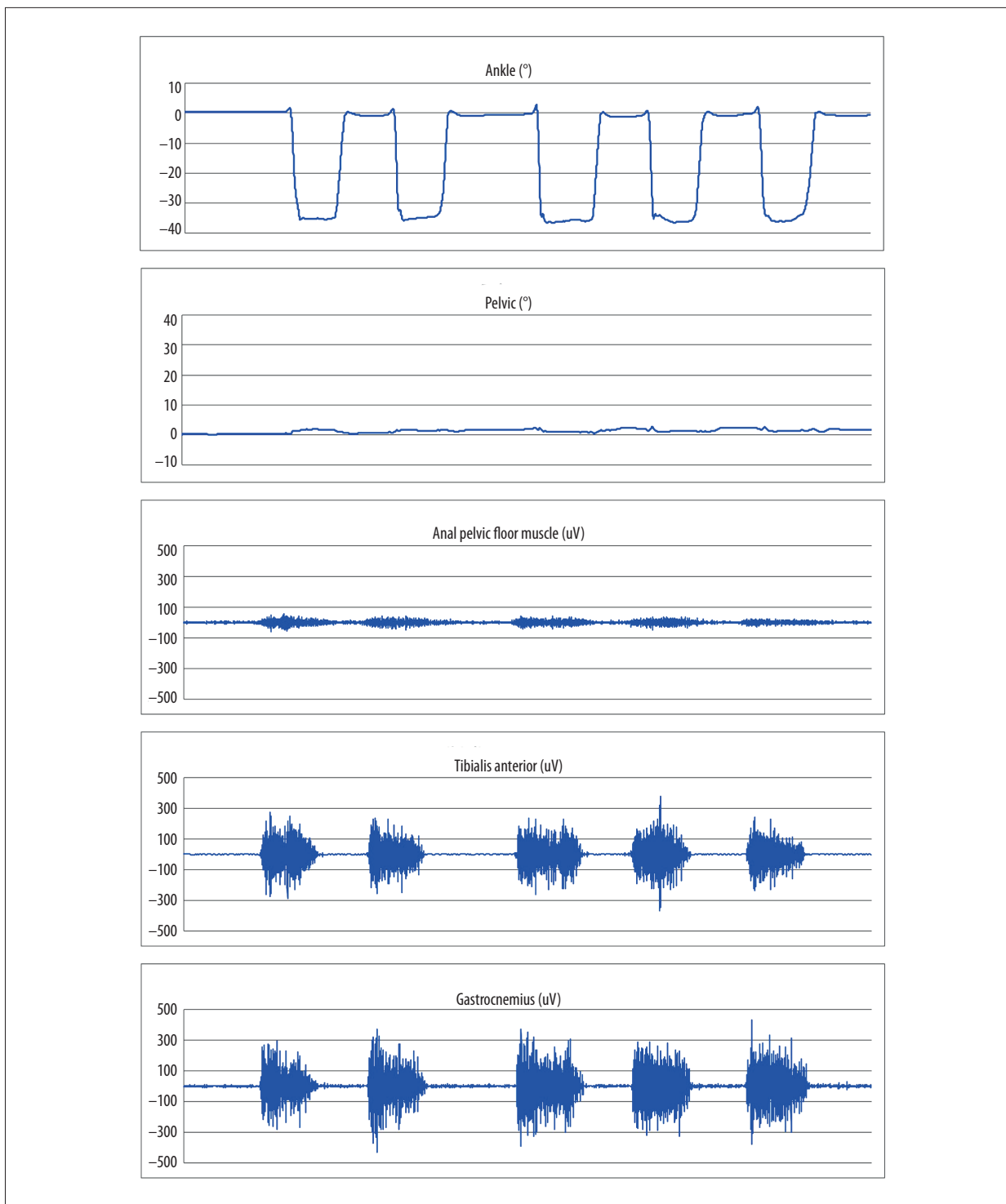


Figure 3. Ankle and pelvic angle and muscle activity in ankle plantar flexion.

muscles were smaller than during ankle dorsiflexion, but were found to be more active during neutral position of the ankle. In the standing posture with ankle plantar flexion, the activity of the anal PFMs increased to 9.63 MVIC% in men and 12.07 MVIC% in women, and 5.94 MVIC% for vaginal PFMs. This

result was not supported by the relationship between pelvic tilt and coccyx motion as proposed in previous studies. Ankle plantar flexion in the standing posture was presumed to co-activate the trunk muscles and PFMs, due to a reduction in the base of support. This must be confirmed by future studies.

Table 2. The comparison of muscle activity with ankle motion (MVIC%).

		Male n=24	Female n=26	Total n=50
Anal pelvic floor muscle	Neutral	11.93±0.94	11.99±0.18	11.96±0.66
	PF	21.56±1.59 ^a	24.06±0.49 ^a	22.86±1.70 ^a
	DF	26.40±2.78 ^{b,c}	39.61±2.91 ^{b,c}	33.27±7.24 ^{b,c}
Vaginal pelvic floor muscle	Neutral		17.44±1.22	
	PF		23.37±1.40 ^a	
	DF		37.54±2.27 ^{b,c}	
Tibialis anterior	Neutral	1.06±0.02	1.45±0.04	1.26±0.20
	PF	30.03±2.15 ^a	10.34±1.48 ^a	19.79±10.10 ^a
	DF	79.76±4.96 ^{b,c}	75.57±2.89 ^{b,c}	77.46±6.79 ^{b,c}
Gastrocnemius	Neutral	3.16±0.13	2.94±0.34	3.05±0.28
	PF	45.59±4.14 ^a	65.18±4.67 ^a	55.78±10.81 ^a
	DF	6.40±1.48 ^{b,c}	9.60±1.46 ^{b,c}	8.75±2.73 ^{b,c}

Values are presented as mean ± standard deviation. PF – plantar flexion; DF – dorsiflexion; MVIC% – maximal voluntary isometric contraction%. Post-hoc analyses significance is reported as follow: ^a *P*<.05 Neutral vs. PF; ^b *P*<.05 Neutral vs. DF; ^c *P*<.05 PF vs. DF.

Previous studies have compared the activation of PFMs during fixed posture of dorsiflexion and plantar flexion and reported that PFMs were activated in dorsiflexion and inactivated in plantar flexion [12,14,16]. Therefore, it was necessary to keep in mind the use of high heels in people with weak PFMs [15]. However, previous studies did not provide adequate information regarding ideal exercise posture to strengthen PFMs.

In this study, activation of PFMs on ankle motion was confirmed by simultaneous real-time analysis. PFM activity increased in the order of neutral, plantar flexion, and dorsiflexion of ankle joint. Therefore, we proved that ankle dorsiflexion position in the standing posture was appropriate for strength training of PFMs. However, it is necessary to confirm whether this effect is confined only to the standing posture or is applicable to all postures.

In this study, we analyzed the effect of PFMs on pelvic and ankle activity through real-time simultaneous analysis using motion analysis and EMG. Results indicated that it was more effective to exercise PFMs in ankle dorsiflexion position, rather than

neutral or plantar flexion position, and we presume that this will be the basis for formulation of effective exercise protocols.

The limitations of this study were that the patients were normal adults and ranged from 20 to 40 years of age. Further investigation is needed to specify general characteristics such as gender, age, birth, and urinary incontinence.

Further research is needed on the coactivation of trunk muscles and PFMs with pelvic tilt, and it is necessary to study the activation of PFMs according to ankle movements in other postures (sitting or prone).

Conclusions

Since ankle dorsiflexion posture led to pelvic anterior tilting, ankle dorsiflexion was found to activate the PFM when performing a PFM exercise in a standing posture. Based on these results, constructing a pelvic floor rehabilitation protocol will be more effective in recovering stress urinary incontinence.

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