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The effects of surface condition on abdominal muscle activity during single-legged hold exercise

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ABSTRACT

To treat low-back pain, various spinal stability exercises are commonly used to improve trunk muscle function and strength. Because human movement for normal daily activity occurs in multi-dimensions, the importance of exercise in multi-dimensions or on unstable surfaces has been emphasized. Recently, a motorized rotating platform (MRP) for facilitating multi-dimensions dynamic movement was introduced for clinical use. However, the abdominal muscle activity with this device has not been reported. The purpose of this study was to compare the abdominal muscle activity (rectus abdominis, external and internal oblique muscles) during an active single-leg-hold (SLH) exercise on a floor (stable surface), foam roll, and motorized rotating platform (MRP). Thirteen healthy male subjects participated in this study. Using electromyography, the abdominal muscle activity was measured while the subjects performed SLH exercises on floor (stable surface), foam roll, and MRP. There were significant differences in the abdominal muscle activities among conditions ($P < .05$), except for left EO ($P > .05$) (Fig. 2). After the Bonferroni correction, however, no significant differences among conditions remained, except for differences in both side IO muscle activity between the floor and foam roll conditions ($p_{adj} < 0.017$). The findings suggest that performing the SLH exercises on a foam roll and MRP is more effective increased activities of both side of RA and IO, and Rt. EO compared to floor condition. However, there were no significant differences in abdominal muscles activity in the multiple comparison between conditions (mean difference were smaller than the standard deviation in the abdominal muscle activities) ($p_{adj} > 0.017$), except for differences in both side IO muscle activity between the floor (stable surface) and foam roll ($p_{adj} < 0.017$) (effect size: 0.79/0.62 (non-supporting/supporting leg) for foam-roll versus floor).

1. Introduction

Low-back pain (LBP) is one of the most common and costly health problems in western societies, with 5–10% of all LBP patients becoming chronically disabled, accounting for 90% of the cost of this condition (Anderson, 1999). Decreased spine stability is one of the most common causes of LBP (McGill et al., 2003; Cholewicki and McGill, 1996; Norris and Matthews, 2008; Hodges and Richardson, 1996). It is suggested that improved control and stability of spine would reduce mechanical irritation and lead to pain relief in LBP patients with spine instability (Panjabi, 1992). The spine stability is achieved by sufficient trunk muscle activation and coordination (McGill et al., 2003).

To treat LBP, various spinal stability exercises without or with therapeutic devices are used to improve the function and strength of the trunk muscles (Behm et al., 2005; Kim et al., 2011; Marshall and Murphy, 2005), which protect the lumbar segments against repetitive microtrauma that could lead to LBP (Davidson and Hubley-Kozey, 2005). In early stage, spinal stability exercise can be enhanced by facilitating a co-contraction and isolated contraction of the muscles surrounding lumbar spine (Richardson et al., 1990). For the exercise progression (dynamic spine stability), spinal stabilization exercise using an unstable surfaces, such as a gym ball or wobble board, have been used to increase the difficulty of spinal stability exercises (Vera-Garcia et al., 2000). An asymmetric load on the trunk muscles induced by a unilateral single-leg-hold (SLH) exercise on an unstable foam roll causes rotation load on lumbar spine,

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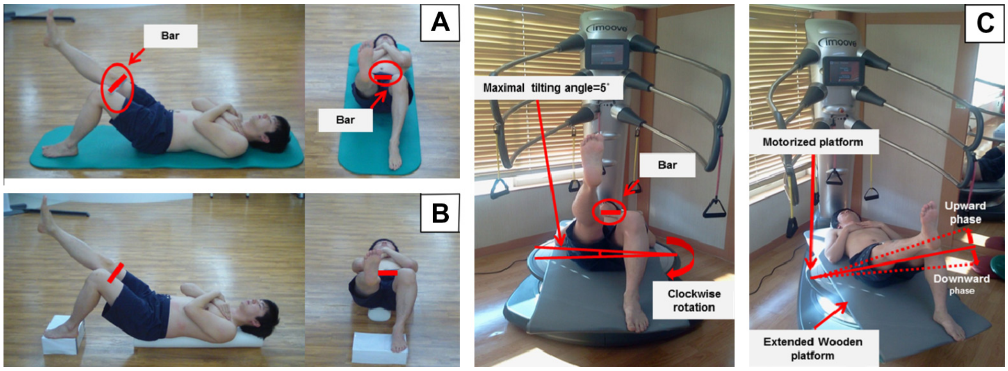

Fig. 1. (A) Floor, (B) foam-roll, and (C) motorized rotating platform.

The subjects were familiarized with each condition for 30 min before testing. During the familiarization period, the principal investigator instructed the subjects to move their non-supporting leg until the predetermined SLH position was reached. The subject was asked to use the fingertips of both hands on the surface to maintain balance. The amount of support from the fingertips decreased gradually over the familiarization period, which finished when the participant could maintain three consecutive 5-s SLH exercises under each condition. All of the subjects were comfortable after the familiarization period, and none reported fatigue. A 15-min rest was allowed after the familiarization period before data collection began. The order of testing was randomized using the random number generator in Microsoft Excel (Microsoft, Redmond, WA, USA). Under each condition, the subject extended the knee joint of non-supporting leg while maintaining knees of supporting leg flexed at 70° and then sustained an isometric contraction of non-supporting leg for 5 s. Three trials were performed with a 1-min rest between trials. A 3-min rest was provided between conditions. The mean value of the three trials under each condition was calculated.

2.4. Data collection and processing

The sampling rate was 1000 Hz. A band-pass filter between 20 and 300 Hz was used. The EMG data were processed into the root-mean-square (RMS) value, which was calculated from 50-ms data windows. To remove noise, motion data were filtered using a second-order zero-lag low-pass Butterworth filter with the 20 Hz of cut-off frequency and EMG data were filtered using a 4th-order zero-lag band-pass Butterworth filter with the 20–300 Hz of cut-off frequency. Before data collection, we performed frequency analysis using FFT (Fast Fourier Transformation) to confirm ECG artifact. However, we did not assure to remove completely ECG crosstalk in the EMG data. The EMG data were normalized by calculating the mean RMS of three trials of a maximum voluntary isometric contraction (MVIC) for each muscle during a 50 ms window about the average activation. We used the manual muscle-testing positions recommended by Kendall and McCreary (2005) for measuring the MVIC. For the RA, the subject was in supine, with hips and knees flexed 90°, feet supported, and trunk maximally flexed (curl-up position), with resistance provided at the shoulders by a tester pushing in the trunk extension direction; for the EO, the subject was in supine, with hips and knees flexed 90°, feet supported, and trunk maximally flexed and rotated to the left, with resistance at the shoul ders by a tester pushing in the trunk ex tension and right rotation directions; for the IO, the subject was in su pine, with hips and knees flexed 90°, feet supported, and trunk maximally flexed and rotated to the right, with resistance at the shoulders by a tester pushing in the trunk extension and left rotation directions. Each contraction was held for 5 s with maximum effort against manual resistance. The first and last second of the EMG data from each MVIC trial were discarded, and the remaining 3 s of data were used (Kim et al., 2011). Three repetitions of each test were performed, with a 2-min rest between repetitions to minimize muscle fatigue (Vera-Garcia et al., 2010). The mean MVIC value of the three trials was calculated.

2.5. Statistical analysis

The SPSS statistical package (SPSS, Chicago, IL, USA) was used to analyze the differences in the RA, EO, and IO muscles. The Kolmogorov–Smirnov Z test were performed to assess whether continuous data approximated a normal distribution. One-way analysis of variance (ANOVA) with repeated measures was used, with the significance level set at .05. When a significant difference was found, Bonferroni's adjustment was used with a significance level of 0.017 (.05/3). The effect size "*d*" was calculated to determine the standardized mean difference between exercises for each muscle. Effect sizes were classified as small ($d = 0.20$), medium ($d = 0.50$), or large ($d = 0.80$) (Portney and Watkins, 2009).

3. Results

The Kolmogorov–Smirnov Z test showed normal distribution in dependent variables ($P > .05$). The normalized EMG data and results of the statistical analyses are shown in Fig. 2. There were significant differences in the abdominal muscle activities among conditions ($P < .05$), except for left EO ($P > .05$) (Fig. 2). After the Bonferroni correction, however, no significant differences among conditions remained, except for differences in both side IO muscle activity between the floor and foam roll conditions ($p_{adj} < 0.017$) (Fig. 2). In our study, the effect size for the RA muscle was 1.04/0.74 (non-supporting/supporting leg) for MRP vs Floor, 0.24/0.03 for MRP vs Foam-roll, 0.77/0.065 for Foam-roll vs Floor. In the EO muscle, the effect size was 0.90/0.65 MRP vs Floor, 0.26/0.02 for MRP vs Foam-roll, 0.73/0.76 for Foam-roll vs Floor. In the IO muscle, the effect size was 0.80/0.67 MRP vs Floor, 0.12/0.20 for MRP vs Foam-roll, 0.79/0.62 for Foam-roll vs Floor.

4. Discussion

This study investigated the effect of surface on bilateral abdominal muscle activity during a SLH exercise performed on the floor, a foam roll, and a MRP. This study showed significant differences in the bilateral abdominal muscles activity among conditions ($P < .05$), except for EO (supporting leg side). Although our results demonstrated differences in abdominal activities among conditions,

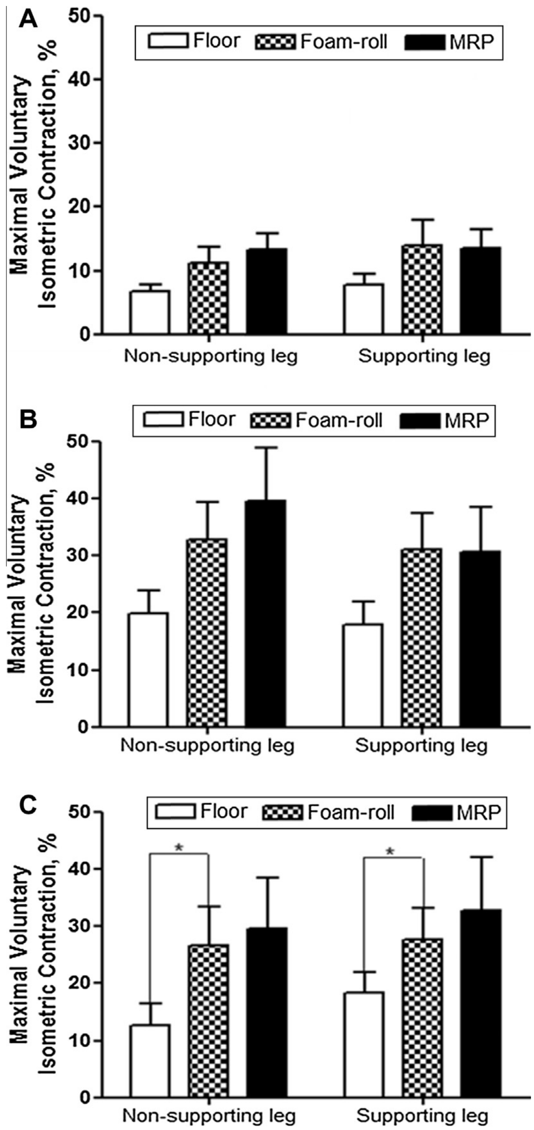

Fig. 2. Comparison of the abdominal muscle activity among 3 different surface conditions. (A) Rectus abdominis muscle, (B) external oblique muscle, and (C) internal oblique muscle. * Significant difference between conditions ($P_{adj} < .017$).

however, there were no significant differences in abdominal muscles activity in the multiple comparison between conditions (mean difference were smaller than the standard deviation in the abdominal muscle activities), except for differences in both side IO muscle activity between the floor and foam roll conditions ($p_{adj} < 0.017$). The results did not support our hypothesis that performing the SLH on MRP condition would elicit greater activity in abdominal muscles than performing it on other condition (see Table 1).

There were several explanations for our results. First, the dynamic rotating surface movement on the MRP and foam-roll can induce a greater perturbation for abdominal muscle activity to maintain spine stability, compared with floor condition. Compared with the floor (stable surface), performing the SLH on a foam-roll or MRP increased perturbation of the spine due to the unstable surface. The results of the present study showed that activity of abdominal muscles greater in unstable surface, which is similar to results of previous studies (Marshall and Murphy, 2005; Vera-Garcia et al., 2000). A unilateral SLH exercise on an unstable foam roll may have caused more lumbar axial rotation, which is more effective at recruiting abdominal muscle activity than is exercise on a floor (stable surface) (Kim et al., 2011). On the MRP, the abdominal muscles expend more effort to maintain the spine stability against the continuous surface tilt change, which can lead to increased joint stiffness to assist counterbalancing body perturbation (Santos and Aruin, 2009). Second, the MRP involves more movement dimensions than other conditions do (*i.e.*, two dimensions for the foam roll, one dimension for the floor), which might contribute to the increased abdominal muscle activity needed to maintain spine stability. Richards and Dawson (2009) reported that multidirectional movement (multi-directional "8" and "∞") was advantageous for muscle strengthening and motor unit recruitment compared with unidirectional exercise. Spine movement occurs in the multi-directions, and abdominal muscles react to multidirectional perturbation for dynamic stabilization of the spine in daily activities (Brown et al., 2006). The devices for multidirectional movement on an oscillating unstable surface were have been recommended to improve balance and abdominal muscle function by in therapeutic program (Kim et al., 2014). Third, an IO muscle contraction increases intra-abdominal pressure, which play key role in maintaining lumbar spine stability because the IO muscle blends with the lateral raphe of the thoracolumbar fascia (Williams et al., 1989). On the MRP and foam-roll conditions with SLH, spine stability is further challenged by surface's perturbation, compared to floor condition (effect size: 0.80/0.67 (non-supporting/supporting leg) MRP vs Floor, 0.79/0.62 for Foam-roll vs Floor). Some variables showed large effect size, however, there was no significant difference in post hoc analysis between conditions (Table 2). These results may due to small sample size and large standard deviation.

Compared with the floor condition (RA: 6.7 ± 3.8%/7.8 ± 5.9%, EO: 19.9 ± 13.1%/18.0 ± 13.1%, IO: 12.6 ± 13.2%/18.4 ± 12.3%), increased abdominal muscles activity was associated with controlling spinal rotation under the foam roll condition (RA: 11.2 ± 8.1%/13.9 ± 13.1%, EO: 32.8 ± 22.2%/31.1 ± 21.2%, IO: 26.7 ± 22.7%/27.8 ± 18.2%) and MRP condition (RA: 13.2 ± 8.9%/13.5 ± 9.6, EO: 39.7 ± 31.1/30.7 ± 26.2%, IO: 29.7 ± 29.5%/32.8 ± 31.0%). To be clinically relevant, the mean difference in muscle activity must be at least 10% MVIC (Reinold et al., 2004). Although there were no significant differences in muscle activity of the abdominal muscles between the foam roll and MRP conditions, activity of abdominal muscles, except for RA and EO in the supporting leg side relatively greater in MRP condition. The supporting leg in the MRP condition was fixed on the moving extended platform, it makes more difficult to maintain stability of supporting leg compared with foam-roll condition. The foot on the fixed floor in foam-roll condition makes easy to maintain stability of supporting leg. Different supporting surface may contribute to increased muscle activity of abdominal muscles, except for or RA and EO in the supporting leg side in MRP condition.

The experimental methods of the present study need further discussion. Although the ECG noise is very common for abdominal muscles activities in EMG study, we did not perform ECG cancellation. The reason is that it is difficult to remove the contamination algorithmically because of the ECG's complicated waveform, which is accompanied by a broad-band spectral distribution. To reduce the effects of the ECG artifact, the ECG should be removed, however, removal of the ECG is complicated since the EMG and the ECG frequency spectrum overlap (surface EMG 20–500 Hz; ECG 0–200 Hz). One difference is that the majority of the power of ECG is found at frequencies less than 45 Hz whereas the peak power for EMG is approximately 100 Hz. In our study, all EMG data were checked visually to ensure that they were valid and not interrupted by artifact from movement or the ECG.

There are some limitations to this study. First, the generalizability of the study is limited because we recruited only healthy male subjects; future studies are necessary to determine whether our

Table 1
EMG activities (%MVIC) of abdominal muscles among 3 different conditions.

Muscle		Condition			F	P
		Floor	Foam-roll	MRP		
RA	NS	6.7 ± 3.8[a]	11.2 ± 8.1	13.2 ± 8.9	4.57	0.02*
	S	7. 8 ± 5.9	13.9 ± 13.1	13.5 ± 9.6	4.38	0.03*
EO	NS	19.9 ± 13.1	32.8 ± 22.2	39.7 ± 31.1	9.13	0.02*
	S	18.0 ± 13.1	31.1 ± 21.2	30.7 ± 26.2	7.13	0.14
IO	NS	12.6 ± 13.2	26.7 ± 22.7	29.7 ± 29.5	8.01	0.03*
	S	18.4 ± 12.3	27.8 ± 18.2	32.8 ± 31.0	5.86	0.02*

RA: rectus abdominal muscle; IO: internal oblique muscle; EO: external oblique muscle; MRP: motorized rotating platform.
[a] Mean ± SD (%MVIC), NS: non-supporting leg; S: supporting leg.
* Significant difference among surface condition ($P < .05$).

Table 2
Multiple comparisons between conditions.

Muscle		Condition comparison	*P*	Effect size
RA	NS	Floor vs foam-roll	0.071	0.77
		Floor vs MRP	0.046	1.04
		Foam-roll vs MRP	1.000	0.24
	S	Floor vs foam-roll	0.087	0.65
		Floor vs MRP	0.035	0.74
		Foam-roll vs MRP	1.000	0.03
EO	NS	Floor vs foam-roll	0.018	0.73
		Floor vs MRP	0.018	0.90
		Foam-roll vs MRP	0.465	0.26
	S	Floor vs foam-roll	0.034	0.76
		Floor vs MRP	0.210	0.65
		Foam-roll vs MRP	1.000	0.02
IO	NS	Floor vs foam-roll	0.007*	0.79
		Floor vs MRP	0.037	0.80
		Foam-roll vs MRP	1.000	0.12
	S	Floor vs foam-roll	0.015*	0.62
		Floor vs MRP	0.123	0.67
		Foam-roll vs MRP	0.901	0.20

RA: rectus abdominal muscle; IO: internal oblique muscle; EO: external oblique muscle, NS: non-supporting leg; S: supporting leg.
* Significant difference between conditions ($P_{adj} < .017$).

findings can be generalized to the patients with LBP and female. Second, this was a cross-sectional study, and a longitudinal follow-up study is warranted to determine the long-term effects of the foam roll and MRP SLH exercise on improving spine stability in LBP patients with spine instability. Third, main limitation of this study is the small sample size and very high variability of the EMG, therefore, the results of the present study have some limitations for generalization. And, we did not filter ECG noise. Therefore, the ECG signal may affect the EMG signals. Fourth, we did not monitor spine motion during the SLH, therefore, we cannot be sure regarding any spine motion that may or may not have occurred during the SLH. Further study is need to measure the spine motions during SLH.

5. Conclusions

This study examined the effects of performing a SLH on a floor (stable surface), a foam roll, or a MRP. The findings suggest that performing the SLH exercises on a foam roll and MRP is more effective increased activities of both side of RA and IO, and Rt. EO compared to floor condition. However, there were no significant differences in abdominal muscles activity in the multiple comparison between conditions (mean difference were smaller than the standard deviation in the abdominal muscle activities) ($p_{adj} > 0.017$), except for differences in both side IO muscle activity between the floor (stable surface) and foam roll ($p_{adj} < 0.017$) (effect size: 0.79/0.62 (non-supporting/supporting leg) for Foam-roll vs Floor).

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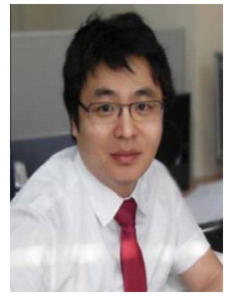

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