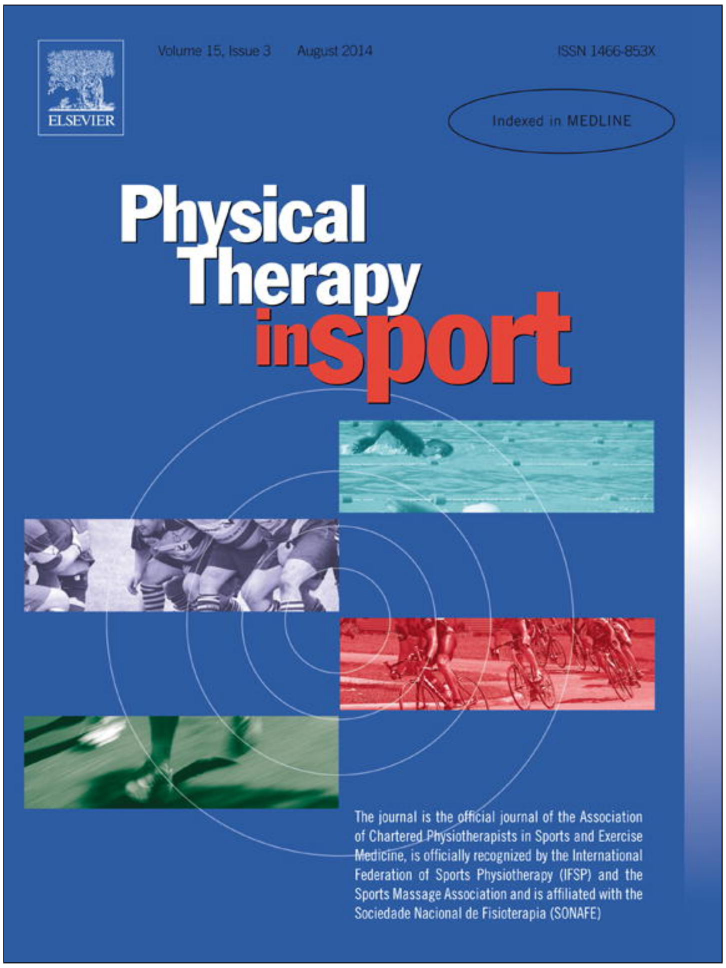
ELSEVIER
Volume 15, Issue 3 August 2014
ISSN 1466-853X
Indexed in MEDLINE
Physical Therapy in sport
The journal is the official journal of the Association of Chartered Physiotherapists in Sports and Exercise Medicine, is officially recognized by the International Federation of Sports Physiotherapy (IFSP) and the Sports Massage Association and is affiliated with the Sociedade Nacional de Fisioterapia (SONAFE)

Physical Therapy in Sport 15 (2014) 162–168

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original research

Abdominal muscle EMG-activity during bridge exercises on stable and unstable surfaces

Dariusz Czaprowski[a,*], Anna Afeltowicz[a], Anna Gębicka[a], Paulina Pawłowska[a], Agnieszka Kędra[b], Carlos Barrios[c,d], Michał Hadała[c,e]

[a] Department of Physiotherapy, Józef Rusiecki University College in Olsztyn, 10-243 Olsztyn, Bydgoska 33, Poland
[b] Department of Posture Correction, Faculty of Physical Education and Sport in Biala Podlaska, Józef Piłsudski University of Physical Education in Warsaw, Poland
[c] Physical Therapy and Exercise Center, Valencia, Spain
[d] Institute for Research on Musculoskeletal Disorders, School of Medicine, Valencia Catholic University, Valencia, Spain
[e] Fizjo-Sport, Rzeszów, Poland

ARTICLE INFO

Article history:
Received 10 September 2012
Received in revised form
24 July 2013
Accepted 18 September 2013

Keywords:
Electromyography
Swiss Ball
BOSU
Core stability
Sport training

ABSTRACT

Objectives: To assess abdominal muscles (AM) activity during prone, side, and supine bridge on stable and unstable surfaces (BOSU, Swiss Ball).
Design: Prospective comparison study.
Setting: Research laboratory.
Participants: Thirty-three healthy volunteers from a university population.
Main outcome measures: Surface electromyography of the rectus abdominis (RA), the external oblique (EO) and the internal oblique with the transversus abdominis (IO-TA).
Results: The AM exhibited the highest activity during prone bridge on a Swiss Ball (RA, EO, IO-TA 44.7 ± 19.2, 54.7 ± 22.9, 36.8 ± 18.6 in % of MVC, respectively). The lowest activity was observed during supine bridge on a stable surface and a BOSU (under 5.0). The lowest ratio analyzed on the basis of the relation of EO and IO-TA activity to RA was obtained during prone bridge on the Swiss Ball (1.4 ± 0.7 for EO, 0.9 ± 0.5 for IO-TA). The highest ratio was obtained during prone bridge on stable surface and supine bridges.
Conclusions: The highest level of activity in the abdominal muscles is achieved during prone bridge on a Swiss Ball. However, this exercise provided the lowest activity of the EO and IO-TA in relation to RA. It is essential to conduct further studies verifying the usefulness of using Swiss Ball during core stability training.

1. Introduction

Lumbar stabilization exercises are a common strategy in recreational and sport training as well as in rehabilitation (Escamila et al., 2010; Imai et al., 2010; Marshall & Murphy, 2005; McGill & Karpowicz, 2009). It might stem from the fact that the proper activation of core stability muscles is essential for accurate functioning of the lumbopelvic complex (McGill & Cholewicki, 2001). The co-activation of trunk muscles is also believed to be important for obtaining a proper trunk stabilization pattern in the treatment and prevention of lower back injuries (Axler & McGill, 1997; O'Sullivan, Phyty, Twomey, & Allison, 1997; Rasmussen-Barr, Ang, Arvidsson, & Nilsson-Wikmar, 2009).

Core stability is defined by two terms – global and local stability systems. The former refers to the larger, superficial muscles (e.g. rectus abdominis) which are the prime movers for the trunk and hip. The latter, local stability refers to the deep, intrinsic muscles of the abdominal wall (e.g. transversus abdominis). This system is responsible for the segmental stability of the lumbar spine during gross whole body movements and where postural adjustments are required (Behm, Anderson, & Curnew, 2002; Hodges & Richardson, 1996; McGill, 2007, pp. 113–123). Recently, attention has been paid to the fact that the activity of rectus abdominis (RA) during stability exercises should be minimal (Marshall & Murphy, 2005; Richardson, Hodges, & Hides, 2004, pp. 31–58; Richardson, Toppenberg, & Jull, 1990). If this is true, training that increases

* Corresponding author. Tel./fax: +48 895260400.
E-mail address: dariusz.czaprowski@interia.pl (D. Czaprowski).

1466-853X/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ptsp.2013.09.003

the activity of RA and changes the synergistic activation patterns between abdominal muscles may not be appropriate as a lumbar stability exercise (Marshall & Murphy, 2005). Although such an approach should be still treated as a hypothesis, supplementing the assessment of activity of individual abdominal muscles with the analysis of their synergistic activity might be interesting and contribute to complementing the discussion on the selection of exercises during stabilizing training.

The use of unstable surfaces, such as the Swiss Ball, is becoming more popular during core stabilizing exercises (Escamilla et al., 2010; Imai et al., 2010; Lehman, Gilas, & Patel, 2008; Lehman, Hoda, & Oliver, 2005; Marshall & Murphy, 2005; Vera-Garcia, Grenier, & McGill, 2000). The purported advantage of these tools is the potential for increased muscular demand required to maintain postural stability (Imai et al., 2010). The response of muscle activity to unstable surfaces may be variable and dependent on the type of exercises or the assessed muscles (Imai et al., 2010; Lehman, Gordon, Langley, Pemrose, & Tregaskis, 2005; Marshall & Murphy, 2005). Some authors confirm that the unstable surface enhances the activities of trunk muscles (Imai et al., 2010; Lehman, Hoda, et al., 2005; Vera-Garcia et al., 2000). Other authors claim that the type of surface, whether stable or unstable, does not notably affect the activity of the trunk stabilizing muscles (Lehman et al., 2008, Lehman, Gordon, et al., 2005). Kavcic et al. maintains that simple exercises on a stable surface are able to activate spine stabilizers while simultaneously minimizing lower back compression and shear forces (Kavcic, Grenier, & McGill, 2004).

Therefore, further research evaluating the influence of a Swiss Ball on muscle activity ought to be conducted (Marshall & Murphy, 2005; Okubo et al., 2010). Such research should also assess other training devices commonly used in sport and rehabilitation. One of those is BOSU (Gamble, 2010, pp. 158–196). Apart from a range of surface types, various types of exercises, such as prone, side and supine bridges, are frequently employed in rehabilitation and sport programs (Gamble, 2010; Imai et al., 2010; Lehman, Hoda, et al., 2005). It is also important to verify their influence on abdominal muscles activity (Ekstrom, Donatelli, & Carp, 2007; Imai et al., 2010; Lehman, Hoda, et al., 2005; Okubo et al., 2010).

The main purpose of the study was to determine the abdominal muscles activity in relation to the type of exercise (prone, side, and supine bridge) and the type of support surface (stable, BOSU and Swiss Ball).

Taking into account the fact that rehabilitation training of the ventrolateral abdominals may be successfully achieved with exercises that minimize activation of the rectus abdominis (Marshall & Murphy, 2005; O'Sullivan, Twomey, & Allison, 1998; Richardson et al., 1990, 2004, pp. 31–58), the identification of such exercises might be also interesting. Therefore, another aim of the study was the evaluation of the ratio which represents the activity of the external oblique and internal oblique with transversus abdominis in relation to the activity of rectus abdominis (Marshall & Murphy, 2005; O'Sullivan et al., 1998).

2. Methods

2.1. Participants

A total of 33 healthy subjects participated in the research. There were 18 women and 15 men with an age range extending from 18 to 29 years (mean 23.2 ± 2.5; height (m) ranged 1.57–1.94, mean 1.74 ± 0.1; weight (kg) ranged 45–93, mean 68.2 ± 13.8; BMI (kg m^{-2}) ranged 17.6–28.3, mean 22.0 ± 2.6). The inclusion criteria for the study group were the absence of low back pain over the previous 12 months and abstention from physical exercise 48 h prior to the examination. For women, the presence of menstruation on the day of examination and a history of pregnancy within the last 12 months were considered as exclusion criteria.

The subjects of the study, read and signed an information and consent form approved by the local Ethics Committee.

2.2. Exercise procedures

Prior to examination, each subject was acquainted with all the exercise protocols. An instructor demonstrated how to correctly perform each task. Then, the subjects completed a pre-test, receiving additional instruction about how the exercises should be performed. Special attention was paid to maintaining a neutral position of the spine and pelvis ensuring better activation of the stabilizing muscles (Suni, Rinne, Natri, Statistisian, Parkkari, & Alaranta, 2006). Next, the subjects repeated the whole set of exercises (exercises assigned randomly by drawing a card with a number of individual exercise) described below three times. Feedback from the examiner was given during the performance of exercises. There was a 1-min rest between each exercise. There was a 4-min break between the series of exercises.

2.3. Description of exercises

Abdominal muscles activity was recorded while holding the body in static bridge positions on a 15-mm-thick stable surface (Thera-Band, Canada), on a BOSU (BOSU® Pro Balance Trainer, BOSU, Ohio, USA) and on a Swiss Ball with a diameter of 65 cm. The exercises were conducted in sports footwear. Measurements started once the subject took the correct position and lasted 5 s (Fig. 1).

2.3.1. Prone bridge on a stable surface (PB)

The subject was asked to stay in a prone plank position (Fig. 1A). Attention was paid to maintaining a neutral position in the hip joints, pelvis and lumbar spine. The feet were placed to match the width of the hip and forearm and acted as support points. The elbows were placed under the glenohumeral joints, and the arms supported the body vertically to the surface.

2.3.2. Prone bridge on a BOSU (PBB)

Similar to the previous exercise, but with the forearms resting on a BOSU (Fig. 1B).

2.3.3. Prone bridge on a Swiss Ball (PBSB)

Similar to the previous exercise, but with the forearms resting on a Swiss Ball (Fig. 1C).

2.3.4. Side bridge on a stable surface (SB)

The subject was asked to take a side plank position on the right forearm (Fig. 1D). The right elbow was under the glenohumeral joint, and the arm remained in a position vertical to the surface. The left palm was resting on the hip.

2.3.5. Side bridge on a BOSU (SBB)

Similar to the previous exercise, but the forearm was placed on a BOSU (Fig. 1E).

The present study disregarded the assessment of muscle activity during side bridge on a Swiss Ball. It resulted from difficulties in maintaining a neutral position of the spine and pelvis by the subjects.

2.3.6. Supine bridge on a stable surface (SuB)

The initial position was crook-lying, with the knees bent 90°, the feet supported on the heels only and the hands on the floor with palms facing down (Fig. 1F). The subject lifted the pelvis until the hip joints were in the neutral position.

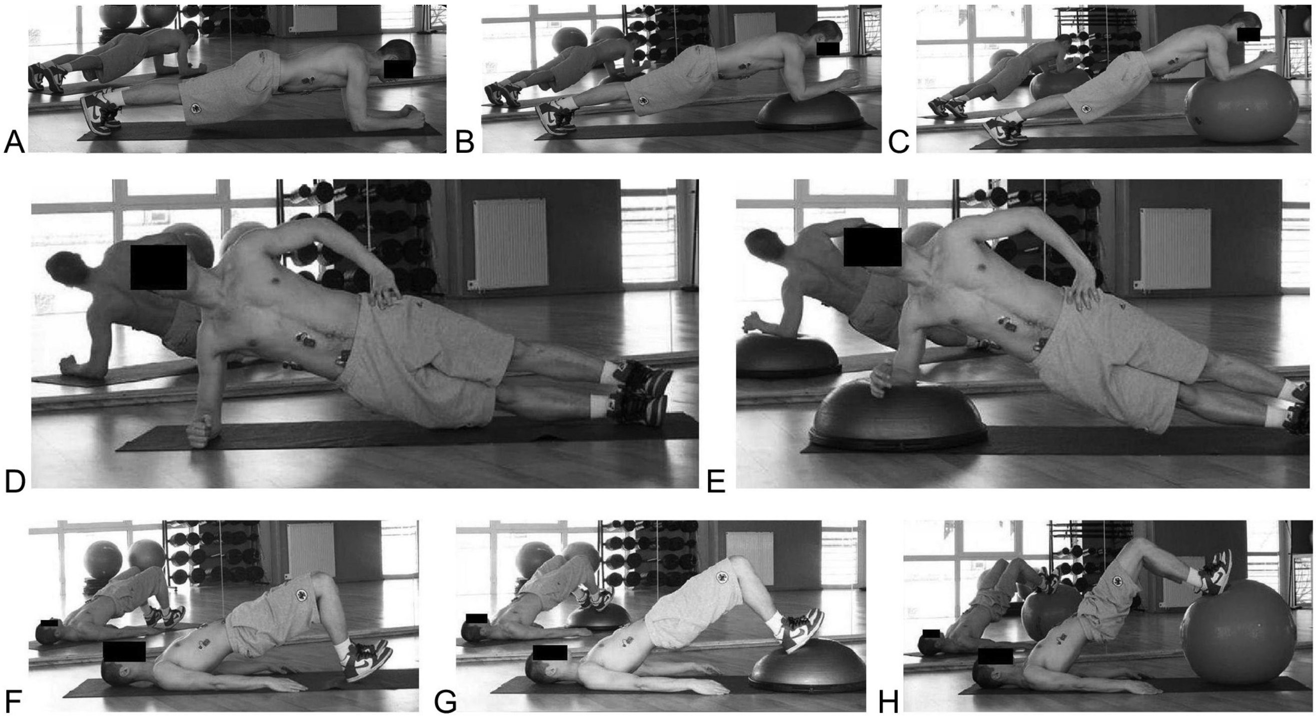

Fig. 1. Exercises used in the study. Prone bridge on a stable surface (A), on a BOSU (B) and on a Swiss Ball (C). Side bridge on a stable surface (D) and on a BOSU (E). Supine bridge on a stable surface (F), on a BOSU (G) and on a Swiss Ball (H).

2.3.7. Supine bridge on a BOSU (SuBB)

Similar to the previous exercise, but with the heels resting on a BOSU (Fig. 1G).

2.3.8. Supine bridge on a Swiss Ball (SuBSB)

Similar to the previous exercise, but with the heels resting on a Swiss Ball (Fig. 1H).

2.4. Data collection and EMG processing

The isometric activity of the rectus abdominis (RA), the external oblique (EO), and the combined activity of the internal oblique and transversus abdominis (IO-TA) only on the right side of the body (Lehman, Gordon, et al., 2005, Lehman, Hoda, et al., 2005; Marshall & Murphy, 2005; Querioz, Cagliari, Amorim, & Sacco, 2010) was recorded. All data signals were registered and measured by means of a surface dynamic electromyography (sEMG) recorder (BTS FREE EMG 300, BTS Bioengeering, Italy) at a sampling frequency of 1000 Hz to 16-bit analog-to-digital conversion, a common mode rejection ratio of greater than 110 dB at 50–60 Hz and an input impedance greater than 10 GΩ. The EMG signals were filtered (bandwidth 10–500 Hz), rectified and subsequently quantified (root-mean-squared (RMS) EMG over a 100 ms window). The device provided completely wireless communication between the preamps and signal collecting unit. To record the RA activity, pairs of electrodes (ARBO, Kendall, Tyco Healthcare, Germany) 1 cm in diameter were placed 5 cm inferior and 3 cm lateral to the xiphoid process (O'Sullivan et al. 1998). For recording the EO activity, electrodes were placed just below the eighth rib's anterior angle, superolateral to the costal margin (Beith, Synnott, & Newman, 2001). To register the IO-TA activity, electrodes were placed 2 cm medial and caudal to the anterior superior iliac spine (Chanthapetch, Kanlayanaphoporn, Gaogasigam, & Chiradejnant, 2009; Marshall & Murphy, 2005). The muscle fibers of the transversus abdominis and internal obliques are blended at this place (Marshall & Murphy, 2003). The electrodes were placed on a thoroughly shaved and cleaned skin with a center-to-center distance of 2 cm, parallel with the muscle fibers (Ekstrom et al., 2007; Lehman, Hoda, et al., 2005).

2.5. EMG normalization procedure

The muscle activity obtained during the exercises was normalized by means of the MVC (Maximal Voluntary Contraction) technique, allowing for the comparison among different subjects (Burden & Bartlett, 1999; Lehman & McGill, 1999; The SENIAM project). For this purpose, each subject held a 3–5-s-long maximal curl up position (for RA) and a bilateral upper-body-twist against manual resistance (trunk rotation to the contralateral side for EO and trunk rotation to the ipsilateral side for IO-TA), and the subject was asked to tighten muscles as much as possible (Beith et al., 2001). The maximal reading was tested in either sitting or crook lying, whichever achieved a greater activity for each subject. The data collected during these tasks, and used for subsequent analysis as a point of reference for all other measurements was from one effort only (Beith et al., 2001). The interval between individual tests amounted to 2 min to prevent muscle fatigue (Chanthapetch et al., 2009). The first muscle assessed was RA, after that EO and IO-TA as the last one.

The average RA, EO and IO-TA activity obtained during each exercise (arithmetic mean of the results from 3 repetitions) was then normalized and expressed as a percentage of the peak activity found in the MVC test.

2.6. Statistical analysis

The data were analyzed using SPSS 18 Statistics Package (Polish version). The data distribution was assessed by the Shapiro–Wilk test. Moreover, descriptive statistics were prepared for each variable (mean ± SD). The comparisons of two or more variables were made using Wilks's Lambda MANOVA omnibus test and the series of Student's *t*-tests with Bonferroni corrections as post hoc.

Bonferroni corrections were calculated for each hypothesis separately with the intention of controlling familywise error rate equal 0.05. Under this premise, the correction was found equal $8 \times (8 - 1)/2 = 28$ for each hypothesis, and the corresponding significance level was 0.0018. Additionally, two ratios of activity were calculated to indicate the relationship between the activity of the EO and the RA and between the IO-TA and the RA (Marshall & Murphy, 2005; O'Sullivan et al., 1998). For comparisons of ratios the one-way ANOVA with Tukey tests as post hoc and Wilcoxon tests were used. The value of $\alpha = 0.05$ was considered as the significance level.

3. Results

3.1. Exercises and surfaces

Table 1 summarizes the average sEMG amplitudes for each abdominal muscle during the evaluated exercises on the different surfaces. During the prone bridge, the RA, EO and IO-TA reached significantly higher activity with exercises on a Swiss Ball compared to the exercise performed on a stable surface ($P < 0.001$) and on a BOSU ($P < 0.001$). The activity of RA and EO significantly increased when the side bridge was performed on a BOSU ($P < 0.001$). The exercises in the supine bridge position induced a low level of EMG activity in all abdominal muscles. Their activity increased significantly when the BOSU and Swiss Ball were used as the surface.

3.2. EMG activity by muscles

The highest activity for the RA was recorded during the prone bridge on a Swiss Ball (44.7 ± 19.2). This activity was significantly ($P < 0.001$) higher compared with all other exercises. The lowest activity was recorded during the supine bridge performed on a BOSU (2.1 ± 1.2) and stable surface (2.2 ± 1.6) (Table 2).

The highest activation of the EO was recorded during the prone bridge performed on a Swiss Ball (54.7 ± 22.9). This activity was significantly higher from these obtained during other exercises (with the exception of side bridge on BOSU). During prone and side bridges performed both on a stable surface and a BOSU, the EO activity was also high (42.3 ± 19.5, 44.8 ± 21.3, 37.6 ± 16.3, and 45.1 ± 20.8, respectively). The lowest activation of the EO was found during the supine bridge exercises on a stable surface (3.9 ± 2.3) and a BOSU (3.8 ± 2.4) (Table 3).

Table 1
Average normalized sEMG amplitudes (%MVC) for each abdominal muscle during the evaluated tasks.

Exercise	Surface	RA	EO	IO-TA
Prone bridge	Stable	18.1 ± 9.1	42.3 ± 19.5	18.5 ± 12.2
	BOSU	20.4 ± 9.5	44.8 ± 21.3	21.3 ± 12.9
Prone bridge	Stable	18.1 ± 9.1	42.3 ± 19.5	18.5 ± 12.2
	Swiss Ball	44.7 ± 19.2*	54.7 ± 22.9*	36.8 ± 18.6*
Prone bridge	BOSU	20.4 ± 9.5	44.8 ± 21.3	21.3 ± 12.9
	Swiss Ball	44.7 ± 19.2*	54.7 ± 22.9*	36.8 ± 18.6*
Side bridge	Stable	16.1 ± 6.7	37.6 ± 16.3	22.8 ± 11.9
	BOSU	18.6 ± 6.8*	45.1 ± 20.8*	25.4 ± 14.2
Supine bridge	Stable	2.16 ± 1.6	3.9 ± 2.3	4.9 ± 3.3
	BOSU	2.06 ± 1.2	3.8 ± 2.4	4.9 ± 3.4
Supine bridge	Stabile	2.16 ± 1.6	3.9 ± 2.3	4.9 ± 3.3
	Swiss Ball	3.53 ± 2.6*	6.6 ± 4.0*	8.9 ± 5.1*
Supine bridge	BOSU	2.06 ± 1.2	3.8 ± 2.4	4.9 ± 3.4
	Swiss Ball	3.53 ± 2.6*	6.6 ± 4.0*	8.9 ± 5.1*

Abbreviations: ±, standard deviation; RA, rectus abdominis; EO, external oblique; IO-TA, internal oblique/transversus abdominis. Significant differences between the surfaces and muscles during each particular exercise. $^{*}P < 0.0018$.

The IO-TA activity during the prone bridge on a Swiss Ball (36.8 ± 18.6) almost doubled that obtained on a stable surface and on a BOSU ($P < 0.001$). The activity of IO-TA during this exercise was also higher compared with other exercises. As in the case of RA and EO, the lowest activity of IO-TA was recorded during the supine bridge exercises (Table 4).

3.3. Ratio of muscle activity compared with the rectus abdominis

The EO/RA ratio was the highest in the prone bridge performed on a stable surface (2.96 ± 2.3) followed by that obtained on the BOSU (2.5 ± 1.2, $P > 0.05$). These results were significantly higher ($P < 0.001$ and $P < 0.013$, respectively) than that obtained on the Swiss Ball (1.4 ± 0.7). During side bridge on the stable surface and the BOSU, the ratio was 2.6 ± 1.3. No difference was found ($P = 0.46$) for the EO/RA ratio among the prone (2.96 ± 2.3), side (2.6 ± 1.3) and supine (2.4 ± 2.0) bridge exercises performed on a stable surface. Similarly, there was no difference between the exercises performed on the BOSU ($P = 0.64$) (Fig. 2A).

The type of surface did not influence the IO-TA/RA ratio in any of the exercises performed in the prone, side and supine bridges ($P > 0.05$) (Fig. 2B). The highest ratios (over 3.0) were found in all exercises performed in the supine bridge position. These ratios were significantly higher ($P < 0.001$) compared with the exercises performed in the prone and side positions (Fig. 2B).

4. Discussion

4.1. Comparison of exercises and surfaces

The prone bridge performed on a Swiss Ball led to significantly higher activity of the RA, EO and IO-TA than during all exercises performed on the other surfaces (with the exception of the EO activity during the side bridge on the BOSU). Lehman et al. also observed that the addition of a ball during prone bridge resulted in increased activity in the rectus abdominis and external oblique. The internal oblique and erector spinae were not influenced (Lehman, Hoda, et al., 2005). Also Vera-Garcia et al. noted increased levels of RA and EO activity while curling the upper body over a gym ball in comparison with the same exercise performed on a stable surface (Vera-Garcia et al., 2000). Thus, researchers concur and confirm that introducing a ball to the prone bridge may lead to increased activity of RA and EO.

The introduction of a BOSU to the side bridge led to a significant increase in the RA and EO activity. According to Imai et al. the unstable surface during side bridge generates greater lateral bending, extension and rotation of the trunk, and, in consequence, the increased muscle activity is associated with controlling these movements (Imai et al., 2010).

In turn, no significant differences were found in muscle activity when the prone and supine bridge were performed on a stable surface or the BOSU.

The supine bridge exercises induced the lowest activation of the examined muscles. However, the use of the Swiss Ball during this exercise involved a significant increase in the RA, EO and IO-TA activity in comparison to the exercises performed on a stable surface or the BOSU. Different observation was shown by Lehman, Hoda, et al. (2005). According to these authors, the addition of a Swiss Ball during supine bridging did not influence trunk muscle activity. The difference between the results obtained by them and the results of the current study might be the consequence of differences in study groups. Lehman et al. evaluated 11 men whereas our study assessed a larger group ($n = 33$) consisting of both men and women. Moreover, subjects evaluated by Lehman et al. presented greater than six months experience in weight training, and

Table 2
EMG activity of rectus abdominis (mean ± standard deviation) and significant differences between the evaluated tasks.

Exercise/mean and ±	PB/18.1 ± 9.1	PBB/20.4 ± 9.5	PBSB/44.7 ± 19.2	SB/16.1 ± 6.7	SBB/18.6 ± 6.8	SuB/2.2 ± 1.6	SuBB/2.1 ± 1.2	SuBSB/3.5 ± 2.6
PB/18.1 ± 9.1	–	0.003	<0.001	0.18	0.7	<0.001	<0.001	<0.001
PBB/20.4 ± 9.5	0.003	–	<0.001	0.008	0.22	<0.001	<0.001	<0.001
PBSB/44.7 ± 19.2	<0.001	<0.001	–	<0.001	<0.001	<0.001	<0.001	<0.001
SB/16.1 ± 6.7	0.18	0.008	<0.001	–	<0.001	<0.001	<0.001	<0.001
SBB/18.6 ± 6.8	0.7	0.22	<0.001	<0.001	–	<0.001	<0.001	<0.001
SuB/2.2 ± 1.6	<0.001	<0.001	<0.001	<0.001	<0.001	–	0.38	<0.001
SuBB/2.1 ± 1.2	<0.001	<0.001	<0.001	<0.001	<0.001	0.38	–	<0.001
SuBSB/3.5 ± 2.6	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	–

Abbreviations: PB, prone bridge on stabile surface; PBB, prone bridge on BOSU; PBSB, prone bridge on Swiss Ball; SB, side bridge on stabile surface; SBB, side bridge on BOSU; SuB, supine bridge on stabile surface; SuBB, supine bridge on BOSU; SuBSB, supine bridge on Swiss Ball.

supine bridge on a ball might not be sufficiently challenging to change muscle activity.

It is also worth noting that the activity of the abdominal muscles obtained during the side bridge on a stable surface and on a BOSU was significantly higher than the activity obtained during all supine bridges.

4.2. Muscle activity

The required level of muscle activity for aerobic training is 30% MVC (Arokoski et al., 1999; Marshall & Murphy, 2005). If we accept as true this assumption, it can be concluded that this condition is achievable by EO regardless of the surface used (stable, BOSU, Swiss Ball) during all prone and side bridges. In the case of the RA and IO-TA, the performance of the prone bridge with the use of a ball was the only condition in which this level of muscle activity was reached. However, it should be underlined that setting the desired muscle activity on the level of 30% MVC during training is not sufficiently supported by research. Therefore, caution should be exercised when directly translating the results obtained in this study into core stabilizing training.

The lowest activity of abdominal muscles was observed during supine bridges. Regardless of the analyzed surface (stable, BOSU, Swiss Ball), this activity was low and less than 10% MVC. These results are supported by the similar observations of Lehman, Hoda, et al. (2005). Bjerkefors et al. also reported that activity of TA during the supine bridge is lower in relation to four-point kneeling with a leg and an opposite arm lifted (Bjerkefors, Ekblom, Josefsson, & Thorstensson, 2010).

4.3. Ratio and clinical relevance

Richardson et al. suggest that the activity of RA during stability exercises should be minimal in comparison to other lumbopelvic muscles (Richardson et al., 1990, 2004, pp. 31–58). This idea might be supported by the suggestion put forward by Edgerton et al. that when a muscle or a group of muscles are weakened, it might evoke shifts in the pattern of motor activity, enabling synergistic muscles to generate the necessary forces required for functional tasks (Edgerton, Wolf, Levendowski, & Roy, 1996). Richardson et al. (1990 and 2004, pp. 31–58) idea may also be confirmed by the fact that individuals with chronic low back pain (LBP) are unable to preferentially activate the IO from that of the RA during the abdominal drawing maneuver (O'Sullivan, Twomey, Allison, Sinclair, & Miller, 1997).

If Richardson's theory is true, increasing the RA activity may not be beneficial for exercises that stabilize the lumbar spine (Marshall & Murphy, 2005; Richardson et al., 1990, 2004, pp. 31–58). Such an approach on synergistic activity of abdominal muscles with minimizing RA activity is interesting. Nevertheless, it ought to be treated with caution due to insufficient evidence supporting this theory. It seems also essential to verify this idea by carrying out observations aimed at evaluating synergistic muscle activity in healthy individuals as well as subjects with LBP while performing various exercises. Such an evaluation may be made by calculating the ratio which determines the activity of EO and IO-TA in comparison with rectus abdominis (Marshall & Murphy, 2005). Marshall et al. used this ratio to assess ventrolateral muscles and erector spinae activity and concluded that quadruped exercises meet the requirements of stabilizing exercises with a minimal level of RA activity (Marshall & Murphy, 2005). O'Sullivan et al. also confirmed that evaluation of the IO activity in comparison to RA is a sensitive means of detecting differences in synergistic muscles activity (O'Sullivan et al., 1998).

In the present study, the exercises with high EO/RA ratio, and simultaneously with muscle activity exceeding 30% MVC were prone and side bridges performed on stable surface and a BOSU.

The highest IO-TA/RA ratio was recorded for the supine bridges. However, the muscle activity in these exercises is low (under 10% MVC). These exercises may be useful for patients with LBP, especially in the initial stages of treatment. The identification of exercises with low muscle activity may also be clinically helpful to grade the load during muscle training (Bjerkefors et al., 2010). The second highest ratio was obtained for the side bridge performed both on a stable

Table 3
EMG activity of external oblique (mean ± standard deviation) and significant differences between the evaluated tasks.

Exercise/mean and ±	PB/42.3 ± 19.5	PBB/44.8 ± 21.3	PBSB/54.7 ± 22.9	SB/37.6 ± 16.3	SBB/45.1 ± 20.8	SuB/3.9 ± 2.3	SuBB/3.8 ± 2.4	SuBSB/6.6 ± 4.0
PB/42.3 ± 19.5	–	0.16	<0.001	0.15	0.39	<0.001	<0.001	<0.001
PBB/44.8 ± 21.3	0.16	–	<0.001	0.04	0.9	<0.001	<0.001	<0.001
PBSB/54.7 ± 22.9	<0.001	<0.001	–	<0.001	0.01	<0.001	<0.001	<0.001
SB/37.6 ± 16.3	0.15	0.04	<0.001	–	<0.001	<0.001	<0.001	<0.001
SBB/45.1 ± 20.8	0.39	0.9	0.01	<0.001	–	<0.001	<0.001	<0.001
SuB/3.9 ± 2.3	<0.001	<0.001	<0.001	<0.001	<0.001	–	0.38	<0.001
SuBB/3.8 ± 2.4	<0.001	<0.001	<0.001	<0.001	<0.001	0.38	–	<0.001
SuBSB/6.6 ± 4.0	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	–

Abbreviations: PB, prone bridge on stabile surface; PBB, prone bridge on BOSU; PBSB, prone bridge on Swiss Ball; SB, side bridge on stabile surface; SBB, side bridge on BOSU; SuB, supine bridge on stabile surface; SuBB, supine bridge on BOSU; SuBSB, supine bridge on Swiss Ball.

Table 4
EMG activity of internal oblique/transversus abdominis (mean ± standard deviation) and significant differences between the evaluated tasks.

Exercise/mean and ±	PB/18.5 ± 12.2	PBB/21.3 ± 12.9	PBSB36.8 ± 18.6	SB/22.8 ± 11.9	SBB/25.4 ± 14.2	SuB/4.9 ± 3.3	SuBB/4.9 ± 3.4	SuBSB/8.9 ± 5.1
PB/18.5 ± 12.2	–	0.002	<0.001	0.07	0.007	<0.001	<0.001	<0.001
PBB/21.3 ± 12.9	0.002	–	<0.001	0.53	0.1	<0.001	<0.001	<0.001
PBSB/36.8 ± 18.6	<0.001	<0.001	–	<0.001	0.001	<0.001	<0.001	<0.001
SB/22.8 ± 11.9	0.07	0.53	<0.001	–	0.003	<0.001	<0.001	<0.001
SBB/25.4 ± 14.2	0.007	0.1	0.001	0.003	–	<0.001	<0.001	<0.001
SuB/4.9 ± 3.3	<0.001	<0.001	<0.001	<0.001	<0.001	–	0.9	<0.001
SuBB/4.9 ± 3.4	<0.001	<0.001	<0.001	<0.001	<0.001	0.9	–	<0.001
SuBSB/8.9 ± 5.1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	–

Abbreviations: PB, prone bridge on stabile surface; PBB, prone bridge on BOSU; PBSB, prone bridge on Swiss Ball; SB, side bridge on stabile surface; SBB, side bridge on BOSU; SuB, supine bridge on stabile surface; SuBB, supine bridge on BOSU; SuBSB, supine bridge on Swiss Ball.

surface and on a BOSU (1.54 ± 0.8, 1.5 ± 0.8 respectively). The IO-TA activity during these exercises was slightly lower (below 30% MVC) than the level proposed by Arokoski et al. (1999).

The introduction of a Swiss Ball to the prone bridge (the exercise with the highest activity of the examined muscles) resulted in the lowest ratio both for EO and IO-TA (1.4 ± 0.7, 0.9 ± 0.5 respectively). It indicates the relatively highest activity of rectus abdominis during this exercise. Having analyzed the ratio during the press-up and top position Marshall et al. also observed a greater relative activity of RA after the introduction of a ball (Marshall & Murphy, 2005).

Thus, taking into consideration the level of muscle activity required for an aerobic training (up to 30% MVC) (Arokoski et al., 1999) as well as the potential benefits of the proper EO/RA and IO-TA/RA ratios, the prone and the side bridge performed on a stable surface and a BOSU might be possibly considered as relevant exercises aimed at lumbopelvic stabilization. Particularly when the decreased activity of RA will be desired during those exercises.

The present work produced similar conclusions as other authors regarding the significant diversity of muscle activity among the subjects (Lehman, Gordon, et al., 2005; Lehman, Hoda, et al., 2005). Concerning EO activity during the prone bridge on a stable surface and on a Swiss Ball, individual reactions to the change of the surface were observed. A group of 28 subjects showed increased activity (with a wide range of EMG activity), and in other 5 subjects, the activity of this muscle decreased. These variations could be related to the fact that some subjects volitionally contracted their muscles to provide stability while some other not. Additionally, the variability may have been due to slight variations in subjects posture and task performance (Lehman, Gordon, et al., 2005; Lehman, Hoda, et al., 2005). The planning of individual therapy should be preceded by an individual examination of the muscle activity during exercises performed on different types of surfaces.

Considering the great number of exercises, the variety of unstable surfaces, and still ambiguous opinions on the influence of unstable surfaces on muscle activity, the research on the EMG activity of muscles stabilizing the lumbopelvic complex should be further addressed. Regardless of results of such studies, it is also worth noting that using an unstable surface may bring more enjoyment during the performance of the exercises, and they also have the potential effect of increasing proprioception (Lehman, Gordon, et al., 2005).

4.4. Study limitations

The current study concluded that the prone bridge performed on a Swiss Ball leads to the low ratio determined by the activity of EO and IO-TA in comparison with RA. However, we should be cautious when translating these observations into training programs since it is vital to undertake further research to determine whether the priority during core stability training should be increasing or minimizing the activity of RA.

The muscle activity was tested only on the right side. It is commonly used in the analysis of EMG activity of trunk muscles (Lehman, Gordon, et al., 2005; Lehman, Hoda, et al., 2005; Marshall & Murphy, 2005; Querioz et al., 2010). However, in this situation the assessment of the muscle activity on the upper side of the body during side bridge was impossible. In further studies, it seems reasonable to assess also the activity of muscles on the other side of the body during this exercise.

Lumbar stabilization exercises may be used in recreational and sport training. However, they may also be used in rehabilitation programs of subjects with LBP. In this case, the limitation of the study was that the assessed subjects did not suffer from LBP. In such patients the same exercises may lead to greater relative muscle activity due to distorted MVC level. This fact should be taken into account when using the results of this study in the treatment of LBP patients.

5. Conclusions

The highest RA, EO and IO-TA activity was obtained during the prone bridge performed on a Swiss Ball. However, this exercise provided the lowest level of activity in the EO and IO-TA in relation

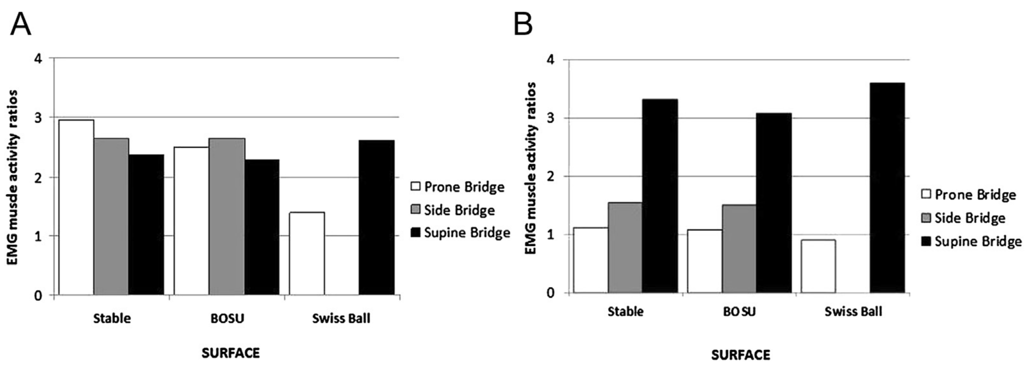

Fig. 2. External oblique/rectus abdominis ratio (EO/RA) (A) and Internal oblique–transversus abdominis ratio (IO-TA/RA) (B).

to the rectus abdominis. The exercises with high EO/RA and IO-TA/RA ratios and simultaneously with high muscle activity were prone and side bridges performed on stable surface and BOSU. The obtained results indicate that it is essential to conduct further studies verifying the usefulness of using Swiss Ball during exercises which aim at training core stability.

Conflict of interest statement

None declared.

Ethical approval

The subjects of the study, read and signed an information and consent form approved by the Józef Rusiecki University College Ethics Committee.

Funding

None declared.

References

Arokoski, J. P., Kankaanpää, M., Valta, T., Juvonen, I., Partanen, J., Taimela, S., et al. (1999). Back and hip extensor muscle function during therapeutic exercises. *Archives of Physical Medicine and Rehabilitation, 80*(7), 842–850.

Axler, C. T., & McGill, S. M. (1997). Low back loads over a variety of abdominal exercises: searching for the safest abdominal challenge. *Medicine and Science in Sports and Exercise, 29*(6), 804–811.

Behm, D. G., Anderson, K., & Curnew, R. S. (2002). Muscle force and activation under stable and unstable conditions. *The Journal of Strength & Conditioning Research, 16*(3), 416–422.

Beith, I. D., Synnott, R. E., & Newman, S. A. (2001). Abdominal muscle activity during the abdominal hollowing manoeuvre in the four point kneeling and prone positions. *Manual Therapy, 6*(2), 82–87.

Bjerkefors, A., Ekblom, M. M., Josefsson, K., & Thorstensson, A. (2010). Deep and superficial abdominal muscle activation during trunk stabilization exercises with and without instruction to hollow. *Manual Therapy, 15*, 502–507.

Burden, A., & Bartlett, R. (1999). Normalisation of EMG amplitude: an evaluation and comparison of old and new methods. *Medical Engineering & Physics, 21*, 247–257.

Chanthapetch, P., Kanlayanaphotporn, R., Gaogasigam, C., & Chiradejnant, A. (2009). Abdominal muscle activity during abdominal hollowing in four starting positions. *Manual Therapy, 14*(6), 642–646.

Edgerton, V., Wolf, S., Levendowski, D., & Roy, R. (1996). Theoretical basis for patterning EMG amplitudes to assess muscle dysfunction. *Medicine and Science in Sports and Exercise, 28*, 744–751.

Ekstrom, R. A., Donatelli, R. A., & Carp, K. C. (2007). Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *Journal of Orthopaedic & Sports Physical Therapy, 37*(12), 754–762.

Escamilla, R. F., Lewis, C., Bell, D., Bramblet, G., Daffron, J., Lambert, S., et al. (2010). Core muscle activation during Swiss ball and traditional abdominal exercises. *Journal of Orthopaedic & Sports Physical Therapy, 40*(5), 265–276.

Gamble, P. (2010). *Strength and conditioning for team sports. Sport-specific physical preparation for high performance*. New York: Routledge.

Hodges, P., & Richardson, C. (1996). Inefficient muscular stabilization of the lumbar spine associated with low back pain: a motor control evaluation of transversus abdominus. *Spine, 21*, 2640–2650.

Imai, A., Kaneoka, K., Okubo, Y., Shiina, I., Tatsumura, M., Izumi, S., et al. (2010). Trunk muscle activity during lumbar stabilization exercises on both a stable and unstable surface. *Journal of Orthopaedic & Sports Physical Therapy, 40*(6), 369–375.

Kavcic, N., Grenier, S., & McGill, S. M. (2004). Quantifying tissue loads and spine stability while performing commonly prescribed low back stabilization exercises. *Spine, 29*, 2319–2329.

Lehman, G. J., Gilas, D., & Patel, U. (2008). An unstable support surface does not increase scapulothoracic stabilizing muscle activity during push up and push up plus exercises. *Manual Therapy, 13*, 500–506.

Lehman, G. J., Gordon, T., Langley, J., Pemrose, P., & Tregaskis, S. (2005). Replacing a Swiss ball for an exercise bench causes variable changes in trunk muscle activity during upper limb strength exercises. *Dynamic Medicine, 4*, 6. http://dx.doi.org/10.1186/1476-5918-4-6.

Lehman, G. J., Hoda, W., & Oliver, S. (2005). Trunk muscle activity during bridging exercises on and off a Swissball. *Chiropractic & Osteopathy, 13*, 14. http://dx.doi.org/10.1186/1746-1340-13-14.

Lehman, G. J., & McGill, S. M. (1999). The importance of normalization in the interpretation of surface electromyography: a proof of principle. *Journal of Manipulative and Physiological Therapeutics, 22*, 444–446.

Marshall, P., & Murphy, B. (2003). The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *Journal of Electromyography & Kinesiology, 13*(5), 477–489.

Marshall, P. W., & Murphy, A. (2005). Core stability exercises on and off swiss ball. *Archives of Physical Medicine and Rehabilitation, 86*, 242–249.

McGill, S. M. (2007). *Low back disorders: Evidence-based prevention and rehabilitation* (2nd ed.). Champaign: Human Kinetics.

McGill, S. M., & Cholewicki, J. (2001). Biomechanical basis for stability: an explanation to enhance clinical utility. *Journal of Orthopaedic & Sports Physical Therapy, 31*, 96–100.

McGill, S. M., & Karpowicz, A. (2009). Exercises for spine stabilization: motion/motor patterns, stability progressions, and clinical technique. *Archives of Physical Medicine and Rehabilitation, 90*, 118–126.

Okubo, Y., Kaneoka, K., Imai, A., Shinna, I., Tatsumura, M., Izumi, S., et al. (2010). Electromyographic analysis of transversus abdominis and lumbar multifidus using wire electrodes during lumbar stabilization exercises. *Journal of Orthopaedic & Sports Physical Therapy, 40*(1), 743–750.

O'Sullivan, P. B., Phyty, G. D., Twomey, L. T., & Allison, G. T. (1997). Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. *Spine (Phila Pa 1976), 22*(24), 2959–2967.

O'Sullivan, P. B., Twomey, L., Allison, G. T., Sinclair, J., & Miller, K. (1997). Altered patterns of abdominal muscle activation in chronic back pain patients. *Australian Journal of Physiotherapy, 43*(2), 91–98.

O'Sullivan, P. B., Twomey, L., & Allison, G. T. (1998). Altered abdominal muscle recruitment in patients with chronic back pain following a specific exercise intervention. *Journal of Orthopaedic & Sports Physical Therapy, 27*, 114–124.

Querioz, B. C., Cagliari, M. F., Amorim, C. F., & Sacco, I. C. (2010). Muscle activation during four pilates core stability exercises in quadruped position. *Archives of Physical Medicine and Rehabilitation, 91*, 86–92.

Rasmussen-Barr, E., Ang, B., Arvidsson, I., & Nilsson-Wikmar, L. (2009). Graded exercise for recurrent low-back pain: a randomized, controlled trial with 6-, 12-, and 36-month follow-ups. *Spine (Phila Pa 1976), 34*(3), 221–228.

Richardson, C., Hodges, P., & Hides, J. (2004). *Therapeutic exercise for lumbopelvic stabilization: A motor control approach for the treatment and prevention of low back pain* (2nd ed.). Sydney: Churchill Livingstone.

Richardson, C., Toppenberg, R., & Jull, G. (1990). An initial evaluation of eight abdominal exercises for their ability to provide stabilization for the lumbar spine. *Australian Journal of Physiotherapy, 36*, 6–11.

Suni, J., Rinne, M., Natri, A., Statistisian, M. P., Parkkari, J., & Alaranta, H. (2006). Control of the lumbar neutral zone decreases low back pain and improves self-evaluated work ability: a 12-month randomized controlled study. *Spine, 31*, E611–E620.

The SENIAM project (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) www.seniam.org (web site access date: 16.01.2012).

Vera-Garcia, F. J., Grenier, S. G., & McGill, S. M. (2000). Abdominal muscle response during curl-ups on both stable and labile surfaces. *Physical Therapy, 80*(6), 564–569.