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Research article

The Effect of Additional External Resistance on Inter-Set Changes in Abdominal Muscle Thickness during Bridging Exercise

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Abstract
Bridging exercises with abdominal hollowing are often used as a regimen for improving spinal stability. Lately, this type of training has become very popular among elite athletes, creating a need for more demanding exercises. The purpose of this study was to investigate whether the use of additional external resistance is beneficial for abdominal muscle recruitment during bridge exercise. Tissue movement of the transversus abdominis (TrA) and the rectus abdominis (RA) was recorded with the use of two synchronized ultrasonic devices, in 20 healthy college students. From the hook-lying position participants were examined in eight different exercise conditions: a) rest, b) abdominal drawing-in maneuver (ADIM), c) bridge, d) bridge- ADIM, e) bridge with 10KG, f) bridge- ADIM with 10KG, g) bridge with 20KG and h) bridge-ADIM with 20KG. Analysis of variance (ANOVA) showed a statistically significant increase in TrA thickness when performing the bridge exercise combined with ADIM compared to rest mode ($p < .05$). RA thickness decreased when the ADIM was performed, compared to rest ($p < 0.05$). No significant difference in TrA and RA thickness when exercising with and without external resistance was observed ($p > 0.05$). The main outcome of this study was that external loading provided some extra level of difficulty, yet it was not beneficial for abdominal muscle recruitment, when performing a supine bridge exercise.

Key words: Transversus abdominis, rectus abdominis, pelvic lift, weight training, ultrasound imaging.

Introduction

It is well established that training of the "core" muscles of the trunk can contribute to the stabilization of the trunk, alleviate the symptoms of chronic low back pain, prevent injuries and possibly maximize sport performance (Akuthota and Nadler, 2004; Leetun et al., 2004; Nesser et al., 2008; Richardson and Jull, 1995). Hence, specific core stability exercises are often incorporated not only in training programs of people who seek rehabilitation, but also in elite athletes' daily training sessions (Wirth et al., 2017).

The "core" of the human body has been described as a complex of muscles, osseous and ligamentous tissues. It can be visualized like a box with its different sides represented by human parts; the abdominal muscles on the front, paraspinals on the back, pelvic floor and hips being the bottom and diaphragm the top cover of this construction (Akuthota and Nadler, 2004). Several muscles are responsible for trunk stabilization, yet each muscle has a different role when spine stability is required, due to their anatomical characteristics. For instance, transversus abdominis (TrA) and multifidus are local muscles with direct attachments to the spine. Hence, their contribution in lumbo-pelvic control is more obvious, even though it is not intuitive. TrA arises from thoracolumbar fascia, last six ribs and iliac crest wraps around the waist like a "corset" and finishes medially in linea alba (Bakkum and Cramer, 2014). When this muscle is activated it produces little to no trunk motion, however its contraction tends to reduce the circumference of the waist and thereby increase intraabdominal pressure and the tension in thoracolumbar fascia (Bakkum and Cramer, 2014). It has been reported that TrA is the first muscle which is activated when there is a lack of stability or a sudden limb movement, in order to prevent excess motion in the lumbar area (Bliss and Teeple, 2005).

Superficial muscles like the rectus abdominis (RA) are main contributors to trunk movement exercises. RA originates from the xiphoid process and 5th, 6th, 7th ribs covering the whole anterior abdominal wall and inserts in the pubic bone. RA's fascicles are usually interrupted by three to five tendinous intersections which add to muscle durability preventing rupture and support the muscle's biomechanics (Rai et al., 2018; Yang et al., 2012). The main function of the RA is to flex the trunk on a fixed pelvis or to flex the pelvis on a fixed trunk (Bakkum AND Cramer, 2014). It has the ability to generate high torques through the thorax and pelvis and when contracting isometrically, it contributes to trunk stability (Lee, 2019).

Many exercises have been described as suitable for strengthening the trunk stability muscles. These include bridge exercises from supine, prone and side positions, bird-dog exercise and many other stability exercises with the use of Swiss balls, BOSSU balls, slings etc. (Bjerkefors et al., 2010; Bliss and Teeple, 2005; Marshall and Murphy, 2005; Saliba et al., 2010). It has been suggested that during core stability exercises, the activation of the RA ideally should be minimal (Czaprowski et al., 2014; Richardsonand Jull, 1995; Urquhart et al., 2005).This assumption has its foundation in two theories. First, "global" trunk muscles, such as the RA, are active overwhelmingly in most trunk flexion dynamic movements and hence, relaxation of this muscle could allow better activation of deep trunk muscles, such as the TRA (Richardson and Jull, 1995). Second, in order to contract the TrA muscle properly, pelvis and spine movement should be minimal, and, thus, the RA activity is low (Richardson and Jull, 1995; Urquhart et al., 2005). This is best achieved when performing an exercise known as abdominal hollowing or abdominal drawing-in maneuver (ADIM), which selectively activates the TrA and the lumbar multifidus but not

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the superficial muscles, like the RA (Richardson and Jull, 1995). In order to perform this technique correctly, one must draw their lower abdomen in, feeling that the navel is getting closer to the spine, while maintaining relaxed abdominal muscles, pelvis and spine (Richardson and Jull, 1995). Research studies have shown that during ADIM performance, TrA muscle's thickness increases significantly (Bjerkefors et al., 2010; Himes et al., 2012; Manshadi et al.,, 2011; Mew, 2009; Nagai et al., 2016; Saliba et al., 2010). Moreover, it has been proposed that improvement of TrA contraction thickness is achieved when using submaximal exercise loads (less than 30% of maximum voluntary contraction) (Hodges et al., 2003; McMeeken et al., 2004). Since local muscles contribute to spinal stability in a different way than global muscles, some researchers advocate that they should be trained separately (Hodges, 1999; Richardson and Jull, 1995**.** Others believe that the design of a core stability training program should follow the principles of progression, starting with simple tasks like the familiarization with proper hollowing execution and gradually incorporating more difficult exercises that recruit not only local muscles but also the superficial ones (Bliss and Teeple, 2005).

Early studies have examined the activation of deep trunk muscles with the use of intramuscular (Bjerkefors et al., 2010; Urquhart and Hodges, 2005) and surface electromyography (EMG) (Czaprowski et al., 2014). The former method requires the insertion of fine wire electrodes in the human body in order to detect the activation of certain muscles, such as the deep trunk muscles. Ultrasound (US) imaging allows a non-invasive visualization of muscle morphology at rest and during exercise (Hodges et al., 2003). This is because muscle architectural parameters (thickness, fascicle length and orientation) change from rest to contraction (Hodges et al., 2003). For deep trunk muscles, where visualization of fascicle length is difficult, changes in thickness from rest to exercise have been considered as being a valid measure of the result of muscle activation (Djordjevic et al., 2015; Ferreira et al., 2004; Hodges et al., 2003; Koppenhaver et al., 2009; McMeeken et al., 2004). In particular, many studies have shown there is a high correlation ($r > 0.74$) between US thickness of the TRA and EMG, with the relationship found to be either curvilinear (Hodges et al., 2003) or linear (Ferreira et al., 2011; McMeeken et al., 2004). Further, there is evidence that changes in US thickness during exercise can be used to discriminate patients with low back pain from controls (Djordjevic et al., 2015; Ferreira et al., 2011). For this reason, changes in thickness have been used to monitor the effects of specific exercises (Baek et al., 2012; Himes et al., 2012; Kim et al., 2017; Mew, 2009) or exercise programs (Cho, 2015; Gong, 2018; Yang et al., 2015) on abdominal muscle function. Due to very low levels of recruitment, changes in RA muscle thickness during core muscle exercises have rarely been examined; there are reports, however, that examined the effects of various trunk exercises on the thickness of RA and the other abdominal muscles (Kim et al., 2015) or they compared children with spasticity and typically developing children (Adjenti et al., 2018). RA muscle thickness has also been used to test the effects of exercise interventions on abdominal muscle function (Romero-Morales et al., 2018). Further, the reliability of US in the measurement of muscle contraction thickness has been extensively investigated in many studies (Gnat et al., 2012; Hides et al., 2007; Koppenhaver et al., 2009).

The majority of studies have focused on the importance of core stability training in alleviating the pain in people with non-specific chronic low back pain and increasing the sensory efficiency of soft tissues (Koppenhaver et al., 2009; Richardson and Jull, 1995; Teyhen et al., 2005). Even though this type of training was designed for individuals with back pain symptoms, it has become quite popular among elite athletes who wish to increase their performance (Sharrock et al., 2011) or to protect their lumbar spine from future injuries. The spread of core exercises in well trained athletes' training routines, has created the need for more challenging exercises and, hence, the existing drills have been modified in different ways in order to raise the difficulty level. These include supine bridge exercises at unstable surfaces (Saliba et al., 2010), exercises using slings and vibration (Gong, 2015), modified trunk curl-up exercises (Crommert et al., 2018) and sit-ups on BOSSU balls with added resistance (Saeterbakken et al., 2014). Among these, the back bridge exercise is a closed kinetic chain exercise which is widely used not only for increasing the muscular strength of the hip extensors, but also for improving lumbar stabilization as it induces the contraction of the abdominal muscles (Baek et al., 2012; Cho, 2015; Gong, 2018; Stevens et al., 2006; Yang et al., 2015). It is not however clear whether core muscle exercises can be classified based on their level of intensity. Himes et al. (2012) reported that TrA thickness does not increase when performing side-bridge exercises of increasing difficulty. In contrast, a bridging exercise utilizing a suspension system has been shown to result in greater TrA thickness changes than a traditional bridge exercise (Saliba et al., 2010), due to increased instability in the lumbar region.

Modern athletes must have the ability to adapt into different conditions, meaning that their muscles, especially the spine stabilizers, should be well trained in order to, either allow more mobility or ensure maximum stiffness depending on circumstances. Despite the rich literature, a parameter that has not been thoroughly examined, that could possibly affect muscle thickness, is the addition of external resistance when performing bridge exercises. Since back bridge exercises are extensively applied for core stability purposes and for strengthening the leg extensors in the form of hip thruster using high loads (Baek et al., 2012; Cho, 2015; Gong, 2018; Stevens et al., 2006; Yang et al., 2015), understanding the role of added weight and ADIM for the abdominal muscles seems worthwhile. For that reason, the primary purpose of the present study was to identify a more challenging core exercise and thus more suitable for athletes' demands, by investigating the effects of added external load, in TrA and RA contraction thickness, during supine bridge exercise, with the use of US. In addition, we examined whether thickness change differed between the RA and TrA during each exercise condition and, finally, whether performing an ADIM after assuming the bridge position would alter muscle thickness. We hypothesized that the use of additional external resistance may reduce the stability levels during back bridge and combining it with an ADIM would induce a greater contraction thickness of the TrA muscle, than in non-weight bearing conditions. Moreover, based on the progression models of earlier studies, external input can be added to increase the exercise stimulus and challenge core stability exercises of well-trained individuals even more (Bliss and Teeple, 2005).

Methods

Our primary purpose was to identify any differences in abdominal muscles' thickness through a series of exercises and especially when extra load was added. Therefore, the participants performed a sequence of exercises with and without adding external resistance. In each condition, muscle thickness was obtained directly using the electronic calipers in the US software. In addition to ultrasound measurements, hip and knee joint kinematics were obtained in 10 individuals for each testing condition.

Participants

A convenience sample of 20 students of a Department of Physical Education and Sport Sciences were recruited for this study. The participants were young adults (age 20.55 ± 1.09 yrs, height 1.80 ± 0.07 m, and mass 78.8 ± 9.3kg) and they were athletes of some kind of sport (soccer n = 7, track and field n = 5, combat sports n = 3, other sports n = 5). Exclusion criteria included history of low back pain in the last 6 months, abdomen or back surgery and any spinal abnormality. Having met the inclusion criteria and given that the purpose of this study was to compare different exercises in asymptomatic individuals, this sample was considered convenient. All participants signed a written informed consent prior to their participation in the research. The protocol was approved by the Ethics Committee of the Aristotle University of Thessaloniki.

Instrumentation

Tissue movement of transversus abdominis and rectus abdominis was recorded with the use of two synchronized ultrasonic (US) devices (SSD-3500, ALOKA, Japan and GE LOGIQ 400 CL PRO, GE Medical Systems, U.K)with a linear array probe of 10 MHz wave frequency and a length of 6 cm. Composite video images were simultaneously obtained using video streaming devices (Avermedia, LGP Lite, New Taipei City, Taiwan) at 30 Hz. Two investigators operated each ultrasound unit and did all the scanning for this study. One of them had 7-year experience in the use of US and the other had finished 1-year practice with specific protocol prior to commencement of this study.

Procedures

Thickness of the two muscles were measured at 8 different testing conditions: 1) Rest, 2) abdominal drawing-in maneuver (ADIM), 3) Bridge, 4) Bridge-ADIM, 5) Bridge with added external resistance of 10 Kg (Bridge10), 6) Bridge with added external resistance of 20 Kg (Bridge20), 7) Bridge-ADIM with added external resistance of 10 Kg (Bridge-ADIM10) and 8) Bridge-ADIM with added external resistance of 20 Kg (Bridge-ADIM20). Participant familiarization included a full demonstration of each exercise. Each participant then performed a minimum of two trials of each exercise under the experimenter's guidance.

Participants were provided standardized instructions regarding the duration and the technique of each exercise. In the Rest condition, the participants were first instructed to hold a hook-lying position (supine position with knees bent at 60° and feet on the bed), placing their arms crossed on the chest. They were asked to breathe normally, avoiding unnecessary movement of the body and muscle contraction. This was also the starting position for the following exercises. In the ADIM, the participants assumed the starting position and breathed normally, and they were then instructed to take one last breath and simultaneously exhale and gently pull their lower abdomen inwards. The verbal guidance was "feel your navel moving towards the spine while keeping the abdominal muscles relaxed" (Richardson and Jull, 1995). In the Bridge exercise, from the hook-lying position, the participants moved their arms next to the body and performed a pelvic lift to the point where shoulders, hips and knees formed a straight line. In the Bridge-ADIM condition, after assuming the Bridge position, participants performed an ADIM maneuver (Figure 1). Bridge and Bridge-ADIM exercises were performed using extra loads of 10kg and 20kg. Loads were provided by placing a weight disc on the area of the pelvis. The weight disc top side was placed and secured on the imaginary line between left and right anterior superior iliac spine, while the bottom side was approximately in the middle of the thighs, depending on participants anatomical structure (Figure 2). Each load was secured with Velcro straps. Participants kept each position for 6 seconds in order US measurements to be taken.

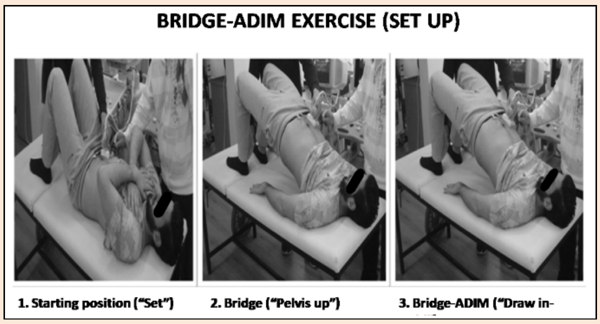

Figure 1. Illustration of the set up for the Bridge-ADIM exercise.

Kinematic analysis

In 10 individuals, reflective skin markers had been placed in the subjects' right side (greater trochanter, femur lateral condyle, lateral malleolus) and video was captured from a video camera (JVC-GR-DVL 9800, frame rate 60 Hz). The camera was set on a tripod at a focal distance of 8 m. The video image of a calibration frame was recorded before each measurement, and 4 calibration points were digitized to determine the 2-dimensional position of any point in space. The coordinates for these markers were digitized using a video-based software (Max Traq Lite version 2.09, Innovision Systems, Inc., Columbiaville, Mich. U.S.A). Subsequently, the hip and knee flexion angles were calculated for each testing condition.

Figure 2. Illustration of the proper weight placement over the hip joint.

Ultrasound measurements

Ultrasound gel was applied liberally to the areas of imaging to ensure good sonic coupling between the transducer and skin. Measurements were taken simultaneously for the RA and the TrA from the participants' left side, since there is not seem to be a side to side difference in lateral abdominal muscles (Gill et al., 2012).

For assessing TrA thickness the tester located the linear probe at the middle of the eleventh costal cartilage and iliac crest, perpendicularly to the midaxillary line, (Hides et al., 2007). To standardize the position of the transducer, the anterior edge of the TrA was positioned approximately 2 cm from the medial edge of the US image, with the subject relaxed. Once the participant assumed the final position, video streaming recording was initiated for a period of 5s. Image was then frozen and TrA muscle thickness was measured using the electronic calipers in the US software (displayed on-screen) as the distance between the superior and inferior hyperechoic muscle fascias, at the middle of the US image (Figure 3). Measurements were conducted perpendicular to the muscle fascias (Hides et al., 2007).

RA thickness assessment was performed using a previously applied protocol (Weis et al., 2015). The linear probe was placed longitudinally at approximately 2cm laterally to the navel, along the midclavicular line (Figure 4). Standardized RA image was achieved by lining the tendinous inscription in the middle of the screen. After freezing the image, RA muscle thickness was measured in the far-left edge of the screen, by taking a vertical measure from the inside edge of the superior fascial border to the inside edge of the inferior fascial border.

Three US measurements were taken in each condition and the mean value was used for further analysis, as it reduces the standard error of the measurement by approximately 50% (Koppenhaver et al., 2009). In addition, for each of the seven exercise conditions, the contraction thickness ratio (CTR) was calculated as the percentage change in muscle thickness relative to rest value. In a previous study, we examined the inter-examiner and intra-examiner reliability of TrA muscle thickness at rest and contraction in young healthy adults and the ICCs ranged from 0.86 to 0.97 at rest, from 0.89 to 0.97 during ADIM and from 0.77 to 0.98 for the CTR (Kellis et al., 2019).

Statistical analyses

The measured data were analyzed using the Statistical Package for Social Sciences (SPSS) ver. 25. Data were checked for normality using the Kolmogorov-Smirnov test. A two-way analysis of variance (ANOVA) design was used to determine the effect of exercise condition (8 levels)

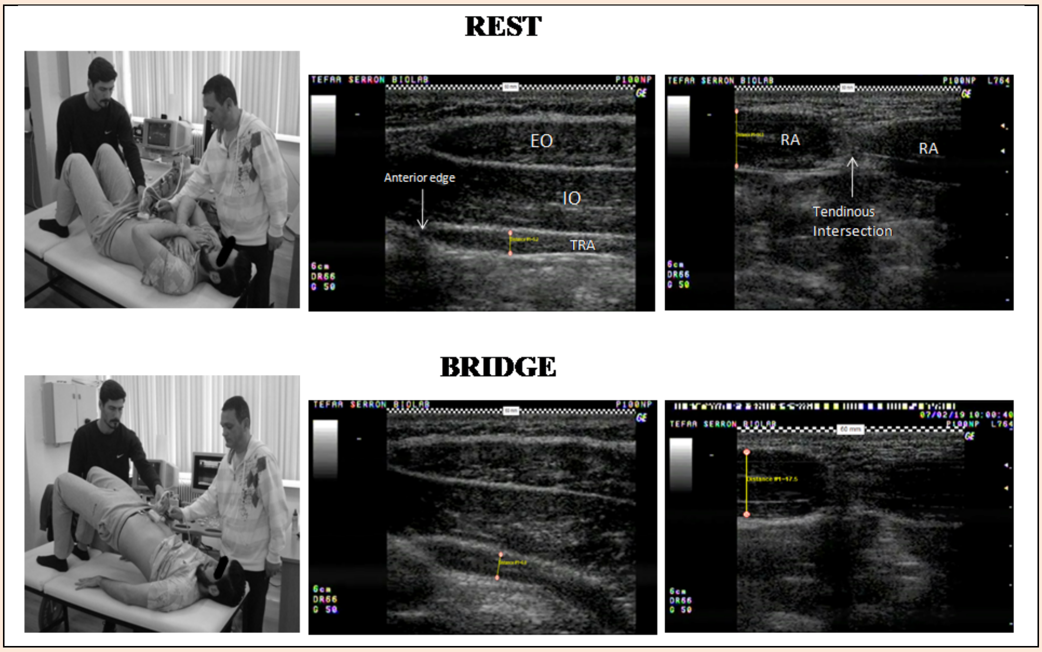

Figure 3. Illustration of the ultrasound measurement technique of the TrA and RA muscles at rest and during contraction (Bridge). Thickness measurements were made between the superficial and deep borders of the TrA and RA muscles.

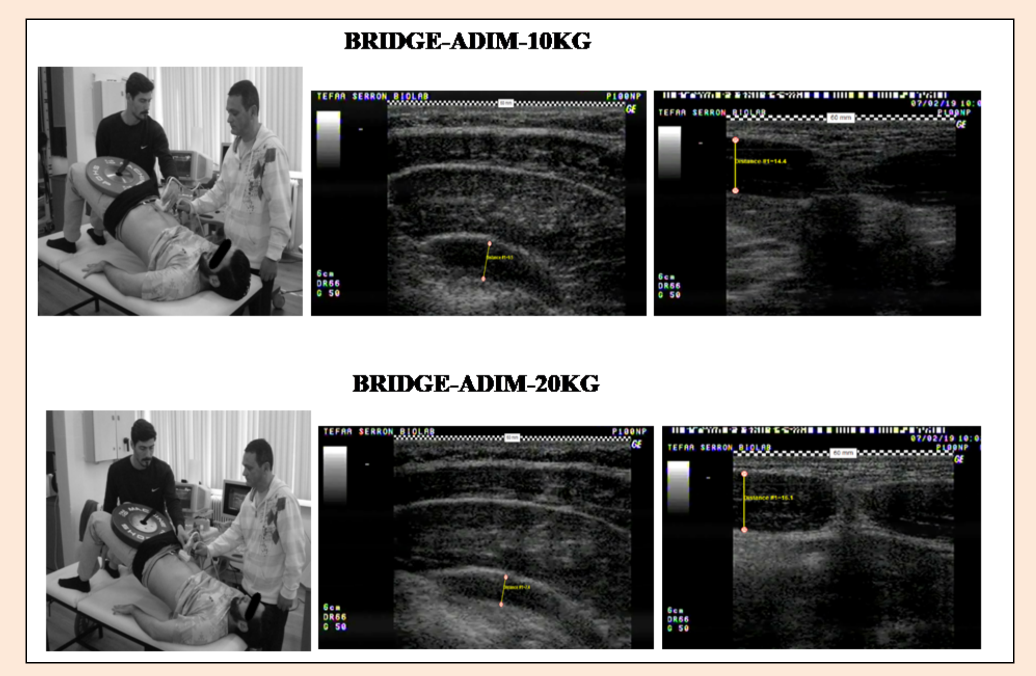

Figure 4. Illustration of the ultrasound measurement technique of the TrA muscle during Bridge-ADIM10 and Bridge-ADIM20. Thickness measurements were made between the superficial and deep borders of the TrA and RA muscles.

and muscle (TrA and RA) on the recorded thickness. A separate two-way ANOVA was applied to examine the difference in CTR between seven exercise conditions and two muscles. The generalized eta squared values (η^2) were calculated as a measure of effect sizes for each independent variable and their interaction. Post-hoc Tukey tests were performed in order to investigate possible differences between exercises, for each muscle separately. Further, to better illustrate the effect of each exercise on thickness, the mean difference in thickness recorded during each exercise relative to resting thickness were also recorded. The level of statistical significance was set to a = 0.05.

Results

Muscle thickness

Mean (± SD) values for RA and TrA muscles thickness at all 8 conditions are presented in Table 1. The ANOVA showed a statistically significant Condition by Muscle effect on muscle thickness ($F_{7.133} = 21.23$, $p < .001$, $\eta^2 = 0.19$). Post-hoc analysis indicated that in each condition, muscle thickness was greater for the RA compared with TrA ($p < 0.05$). For both muscles, Bridge, Bridge10 and Brigde20 did not significantly differ ($p > 0.05$). Similarly, no differences were found in RA thickness between Bridge-ADIM, Bridge-ADIM10 and Brigde-ADIM20 ($p > 0.05$). Compared to rest, TrA thickness significantly increased by more than ~37% when performing the ADIM, Bridge-ADIM with and without the addition of 10 and 20 Kg load (Table 1, $p < 0.05$). Further, performing the same exercise with and without ADIM significantly increased TrA thickness (approximately 3-5 times) at all testing conditions ($p < 0.05$).

The RA rest thickness value was significantly higher than the value obtained during the ADIM ($p < 0.05$) but it was no different than thickness recorded at the other exercise conditions ($p > 0.05$). With one exception (Bridge-ADIM10 was lower than Bridge10thickness), all other pair comparisons in RA thickness were not statistically significant ($p > 0.05$).

Contraction thickness ratio

Group values of CTR at 7 conditions are presented in Figure 5. The ANOVA showed a statistically significant Condition by Muscle effect on CTR ($F_{6.114} = 32.04$, $p < 0.001$, $\eta^2 = 0.24$). Post-hoc analysis indicated that in each condition, CTR was greater for the RA compared with TrA ($p < 0.05$).

Table 1. Mean (± SD) thickness of the transversus abdominis (TRA) and rectus abdominis (RA) in each testing condition. Mean percentage (%) differences (± standard error of measurement) between each exercise and resting condition are also reported.

Condition	TRA (mm)	% difference compared to rest	RA (mm)	% difference compared to rest
Rest	4.57 ± 0.79		14.80 ± 2.34	
ADIM	6.26 ± 0.94	36.98 ± 3.5	13.57 ± 2.36	-8.31 ± 1.89
Bridge	4.84 ± 0.67	5.9 ± 3.28	15.14 ± 2.44	2.22 ± 2.9
Bridge-ADIM	6.72 ± 1.07	47.04 ± 4.15	14.67 ± 3.03	-0.87 ± 2.9
Bridge10	5.06 ± 0.84	10.72 ± 4.37	15.11 ± 2.77	2.02 ± 2.36
Bridge-ADIM10	6.86 ± 0.99	50.10 ± 4.59	14.16 ± 2.83	-4.32 ± 2.22
Bridge20	5.09 ± 0.84	11.37 ± 4.81	15.33 ± 2.85	3.51 ± 3.37
Bridge-ADIM20	6.65 ± 1.43	45.51 ± 6.34	14.44 ± 2.73	-2.43 ± 2.7

N= 20, ADIM= Abdominal drawing-in maneuver, Bridge= pelvic lift, Bridge-ADIM = Bridge with ADIM, 10 = exercise performed with additional resistance of 10 kg,20 = exercise performed with additional resistance of 20 kg

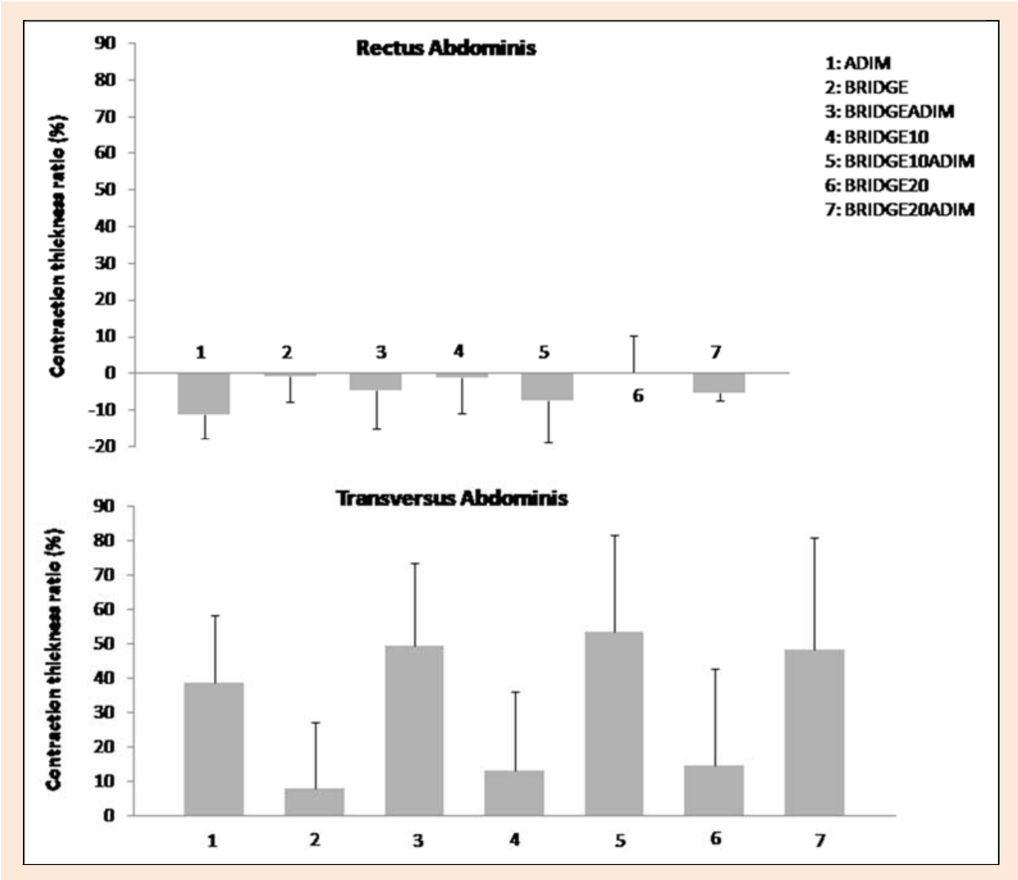

Figure 5. Mean group values of the contraction thickness ratio (CTR) of the transversus abdominis (TrA) and rectus abdominis (RA) in each exercise condition.

For both muscles, CTR in Bridge, Bridge10 and Brigde20 did not significantly differ ($p > 0.05$). Similarly, no differences were found in RA CTR between Bridge20 and Bridge-ADIM20 ($p > 0.05$). For TrA muscle, CTR significantly increased only when ADIM was performed in the following pair comparisons ADIM > Bridge, Bridge-ADIM > Bridge, Bridge-ADIM10 > Bridge10 and Bridge-ADIM20 > Bridge20 ($p < 0.05$). On the other hand, for the RA muscle CTR was significantly lower when ADIM was executed in the following pair comparisons Bridge >ADIM, Bridge-ADIM < Bridge10 and Bridge-ADIM10 < Bridge20 ($p < 0.05$).

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Table 2. Mean (± SD) hip and knee flexion angle at different testing conditions. Asterisk indicates significant difference compared with rest and ADIM at p < 0.05).

	Hip flexion (°)	Knee flexion (°)
Rest	56.70 ± 2.49	90.50 ± 1.64
ADIM	57.50 ± 1.71	88.91 ± 1.52
Bridge	5.44 ± 3.27*	89.40 ± 2.02
Bridge-ADIM	2.52 ± 2.02*	89.72 ± 2.21
Bridge10	6.53 ± 3.54*	90.10 ± 2.55
Bridge-ADIM10	3.88 ± 3.92*	90.60 ± 2.21
Bridge20	6.77 ± 3.66*	89.50 ± 3.62
Bridge-ADIM20	3.96 ± 3.69*	89.40 ± 3.02

ADIM= Abdominal drawing-in maneuver, Bridge= pelvic lift, Bridge-ADIM = Bridge with ADIM, 10 = exercise performed with additional resistance of 10 kg, 20 = exercise performed with additional resistance of 20 kg

Kinematic analysis

Hip and knee flexion angle results are shown in Table 2. The ANOVA showed a statistically significant difference in hip flexion angle between conditions ($F_{7.63} = 567.01$, $p < 0.05$, $\eta^2 = 0.89$). Post-hoc analysis showed that hip flexion angle at rest and ADIM were significantly greater compared with values recorded at the rest exercise conditions ($p < 0.05$). In contrast, no significant differences in knee flexion angle between various conditions were found ($F_{7.63} = 0.86$, $p > 0.05$, $\eta^2 = 0.09$).

Discussion

The main findings of this research study were first, that, performing bridge and ADIM exercises with additional external weight resistance increased TrA thickness but it did not influence RA thickness. Second, all exercises were accompanied by an increase in TrA CTR while the RA CTR either decreased or remained similar. Finally, performing an ADIM while being in the bridge position yielded greater TrA thickness but it did not influence RA thickness and CTR.

The external resistance did not affect TrA and RA thickness in any of the exercises (Table 1). To our knowledge, there are no previous studies that examined the effects of an external weight on muscle thickness during bridge and ADIM exercises. Nevertheless, the present results support those reported by Himes et al. (2012) who did not observe any difference in TrA thickness when performing side bridge exercises of increasing difficulty. There are various factors that may have contributed to the failure to increase thickness by adding external weight while performing bridge exercises. As it was earlier stated, it has been suggested that TrA contraction thickness does not increase more after reaching 20-30% of maximum voluntary contraction (Hodges et al., 2003; McMeeken et al., 2004). This level of effort may have been achieved when performing Bridge-ADIM, so increases beyond baseline would be difficult to detect (Figure 4). There is also the possibility that increasing exercise intensity by adding more external weights may have led to activation of other muscles in order to support the body. However, the fact that a muscle's thickness remains stable during a contraction (isometric contraction), does not necessarily mean that strength gains will not be observed as a result of training (Jones and Rutherford, 1987). Finally, there is a possibility that minor adjustments in trunk position due to external weight did not influence abdominal muscle activation. As for the RA muscle, since it is not the main contributor for the pelvic lift from supine position, the added resistance did not put any stress on this muscle, either. In contrast to our results, Saeterbakken et al., (2014) observed an increased activation of the RA muscle when external resistance was added, but that was during a sit-up exercise protocol, a more straightforward task for the main trunk flexor muscle.

The second finding of this study was that during all exercise conditions, TrA thickness increased while RA thickness remained unchanged or decreased (Table1). To our knowledge, no studies have simultaneously examined RA and TrA thickness using US. Nevertheless, the present results are in accordance with the intramuscular EMG study by Bjerkefors et al., (2010) who showed that during supine bridge, with and without instruction to hollow, TrA muscle was activated independent of the RA muscle. Urquhart et al. (2005) also observed a high TrA activation with minimal RA activity, during inward movement of the lower abdominal wall. Our results extend these observations as selective increase of TrA thickness during bridge exercises was observed even when these exercises were performed against additional external weights.

It has been proposed that during core training, ideally, only local muscles responsible for segmental stability, should be contracted (Hodges, 1999; Richardson and Jull, 1995). Of course this depends on the type of exercise; for instance, during back bridging and abdominal hollowing there is an isolated TrA contraction, whereas in prone bridging exercises, abdominal bracing and curl-ups, a combined activation of the abdominal muscles is needed (Czaprowski et al., 2014; McGill, 2001; Saeterbakken et al., 2014).

The results of this study showed that performance of the ADIM caused an increase in TrA thickness and a reduction in RA thickness compared to rest (Figure 4). The latter might have occurred because during the abdominal hollowing, the lower abdomen is pulled towards inside and thus forcing the anterior abdominal muscles to stretch. Nevertheless, it was clear that almost all participants managed to contract their TrA independently from RA, by using abdominal hollowing. Previous studies have also showed that healthy individuals can activate their TrA muscles predominantly with the use of this maneuver (Baek et al., 2012; Bjerkefors et al., 2010; Mew, 2009). More specifically, it has been reported that bridging exercises induce contraction of TrA, but when these exercises are performed in conjunction with abdominal hollowing an even greater TrA thickness/activation is triggered. Bjerkefors et al. (2010) showed that healthy individuals who perform bridging exercises can increase TrA activation as much as 3 times if they add abdominal hollowing. Similarly, Baek et al. (2012) compared the effects of bridge exercise with and without instruction to hollow on TrA muscle thickness, with the use of US. They observed a greater "activation" ratio (contraction thickness/rest thickness) of TrA, for the group that performed bridge exercise combined with ADIM. Cho (2015) also observed a positive impact of a 6-week training program of a bridge exercise accompanied by ADIM on TrA thickness. They proposed that bridge exercise must be preceded by abdominal hollowing in order to prevent excessive lumbar lordosis. The incorporation of ADIM appears to be beneficial for TrA muscle recruitment not only while executing different tasks (Kim et al., 2017; Lee, 2019), but also when assuming various postures (Manshadi et al., 2011; Nagai et al., 2016). Our results add up to these observations as it appears that performing a bridging exercise with external resistance is a less efficient stimulus for TrA thickness than performing the same exercise in combination with ADIM. Consequently, it appears that the most important element, when it comes to TrA activation, is the ADIM technique.

Limitations

There are several limitations in this study. The results are specific to physically active individuals with no classification of LBP in the last 6 months. It is possible that abdominal thickness may differ if individuals with LBP or professional athletes are examined. In addition, in this study the activation or thickness of other muscles, such as the oblique abdominals or the glutei muscle was not recorded. Monitoring the activation of more muscles may have provided a better understanding of the role of external weights for the effectiveness and exercise progression of bridging exercises. We have made every effort to stabilize the external weight during exercise. Securing external bars in the abdominal and pelvic area is not always easy and may create instability of the body after assuming the bridging position**.** In addition, a limitation of this study is that the weight disc was not placed directly over the hips in order to load effectively this area, but it was lowered towards the thighs. This position was selected in order to ensure proper position of the US probes over the abdominal muscles during exercise. We have selected this type of external resistance as it can be easily adapted in practice. Further, to avoid any movement deviations that occurred in participants when they perform bridging exercises, data collection started after the participant assumed the bridging position. US thickness of one side was quantified while measures were made on the US machine during imaging acquisition, rather than using a separate imaging analysis software. Finally, although US thickness change was demonstrated to be highly correlated with EMG measurements (Djordjevic et al., 2015; Ferreira et al., 2011; Hodges et al., 2003; McMeeken et al., 2004), US thickness measurement during contraction is a measure of the result of activation and not the activation itself.

Conclusion

Back bridge exercises, especially with external weights load the hip musculature (Baek et al., 2012; Cho, 2015; Gong, 2018; Stevens et al., 2006; Yang et al., 2015). Further, such exercises are frequently used to activate the abdominal muscles, by performing the ADIM maneuver after the participant have assumed the bridge position. The results of this study indicated that the additional external resistance when performing bridge and ADIM exercises is not beneficial for increasing abdominal muscles contraction thickness. Bridge and ADIM exercises in various combinations caused an increase in TrA thickness while RA thickness was unchanged or even reduced. This implies that, the actions of lifting the pelvis and drawing the lower abdomen in, were responsible for the greater TrA activation and not the extra load. Fitness and physical performance professionals have been applying these exercises, extensively, in order to improve their athletes' core muscle function. However, when there is a need for progressiveness, external loading is not the ideal tool, at least when it comes to TrA abdominal muscles thickness. Strength and conditioning coaches should focus on the proper execution of the ADIM in bridging exercises rather than adding external resistance. Furthermore, such exercises do not influence RA thickness at all, even when they are performed with an additional external weight.

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Key points

- Bridge exercises with ADIM increase TrA muscle's thickness.
- External resistance during back bridge exercise do not affect abdominal muscles.
- Abdominal hollowing reduces RA muscle's thickness.

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