Prevention and Rehabilitation

Comparison of linea alba length and core-muscles engagement during core and lower back orientated exercises

Q5

Q4

The corrections made in this section will be reviewed and approved by a journal production editor.

Q1 Rodrigo Rico Bini* r.bini@latrobe.edu.au, Alice Flores Bini

La Trobe Rural Health School, La Trobe University, Bendigo, Australia

Q2 *Corresponding author. . La Trobe Rural Health School, La Trobe University, Flora Hill Campus, 3550, Australia.

Abstract

Background**:** A comparison of Linea Alba (LA) length and engagement of the Transverse Abdominis (TrA), External Oblique (EO) and Internal Oblique (IO) between core-orientated and lower back orientated exercises (e.g. glute bridge and hip extension) is not lacking. Therefore, the aim of this study was to compare the length of the LA and the engagement of TrA, EO and IO when performing the prone plank, bird dog, dead bug, lateral plank, glute bridge and hip extension.

Methods**:** Thirteen apparently healthy participants volunteered to this study. Ultrasound scanning of the anterior and antero-lateral walls at baseline and whilst performing prone plank, bird dog, dead bug, lateral plank, glute bridge and hip extension exercises was performed. LA length and thickness of the TrA, EO and IO were measured from ultrasound images.

Results**:** LA length ($p = 0.77$) and TrA thickness ($p = 0.23$) were not different between exercises. EO thickness was larger for the lateral plank compared to the bird dog ($p = 0.01$, $d = 1.73$), glute bridge ($p < 0.01$, $d = 2.64$), and hip extension ($p < 0.01$, $d = 1.89$). The dead bug was also larger in comparison to the glute bridge ($p < 0.01$, $d = 2.05$) and to the hip extension ($p = 0.01$, $d = 1.45$). For the IO thickness, the lateral plank was larger than the bird dog ($p = 0.03$, $d = 1.21$) and the dead bug ($p = 0.04$, $d = 1.12$).

Conclusion**:** No difference was observed between exercises for the length of the LA or for the thickness of the TrA, which suggests that this muscle is similarly engaged in the assessed exercises, leading to a consistent stretch for the LA.

Keywords:

Ultrasound, Diastasis recti abdominis, Core-muscles, Muscle thickness

1 Introduction

The core consists of 29 pairs of muscles with a key role of assisting in the stabilization of the spine, pelvis and kinetic chain during functional tasks (Faries and Greenwood, 2007; Fredericson and Moore, 2005). The core muscles can be further broken down into two sub-groups. Muscles superficial to the spine, termed ‘global muscles’ (i.e. rectus abdominis, longissimus, iliocostalis and latissimus dorsi); which are able to generate large amounts of torque (Hodges, 2003). The other group of muscles that are located more deeply consist of the transverse abdominis (TrA), and external (EO) and internal oblique (IO); which are often classified as 'local stabilizing muscles' (Chang et al., 2015). These muscles protect the spine, reduce the load on the lumbar vertebrae and intervertebral discs, and facilitate stability during movement (Huxel Bliven and Anderson, 2013).

For those who suffer from low back pain, one variable that potentially plays a role is the strength and stability of the core muscles (Chang et al., 2015). Of the local stabilizing muscles, the role of the TrA has been thought to have a correlation between spinal stability and low back pain (Hodges, 1999). It is believed that a major role of the TrA is in preventing excess movement and increasing intraabdominal pressure to help stabilize the spine (Cresswell et al., 1992). Studies have examined the role of the TrA in facilitating stabilization of the lumbar pelvic region and thus in improving symptoms in pain or function in populations with chronic low back pain (França et al., 2010; Hosseinifar et al., 2013; Miller et al., 2005).

Diastasis Recti Abdominis is a condition experienced by pregnant and post-partum women and in some men (Moesbergen et al., 2009) where the midline separation between the left and right sections of the rectus abdominis muscle increases. This increase can be in excess of 2 cm at the level of the umbilicus and is accompanied by an extension of the Linea Alba tissue and bulging of the abdominal wall (Benjamin et al., 2014; Mota et al., 2015). Functionally, this can result in a lateral elongation of the rectus abdominis, leading to the stretching and flaccidity of the Linea Alba (Coldron et al., 2008). Consequently, spinal stability is largely diminished due to the lengthening of the abdominal muscles with changes observed in these muscles' ability to generate tension ensue. This can cause lower back pain, hip pain, herniations and the development of trunk mechanic alterations, leaving the lumbar spine and pelvis more susceptible to injury (Axer et al., 2001; Parker et al., 2009).

Investigating the engagement of the TrA, EO and IO is essential to understand their contribution to low back pain, which is commonly performed using ultrasound and electromyography (Martuscello et al., 2013; Rasouli et al., 2011; ShahAli et al., 2019). The benefits of the ultrasound are that each muscle can be identified individually, without cross-talks normally observed in surface EMG data of deep muscles (Beazell et al., 2011) and that indwelling electromyography would not be required to measure the engagement of deep muscles (i.e. TrA).

Of the common exercises prescribed for managing low back pain, the prone plank, bird dog and lateral plank have been indicated (Ekstrom et al., 2007). The bird dog and lateral plank are also endorsed in their ability to provide stabilization to the spine (McGill, 1998) and the dead bug has been described as an exercise to help train the control of the abdominal postural muscles (Carpes et al., 2008). However, given most of the evidence on the engagement of deep muscles have been obtained using EMG, data from ultrasound is lacking. In addition, the comparison of the prone plank, bird dog and lateral plank with exercises orientated for the engagement of lower back muscles (e.g. glute bridge and hip extension) is not available. Moreover, no evidence on the change in length of the Linea Alba when performing these exercises is available.

Therefore, the aims of this study were to: 1) compare the length of the Linea Alba when performing the prone plank, bird dog, dead bug, lateral plank, glute bridge and hip extension and 2) compare the engagement of TrA, EO and IO using ultrasound whilst performing the aforementioned exercises.

2 Methods

2.1 Study design

This study was conducted and reported in line with guidelines from STROBE (Strengthening the Reporting of Observational Studies in Epidemiology, http://www.equator-network.org/reporting-guidelines/strobe/). A cross-sectional cross over design was employed in this study to assess the acute changes in engagement of TrA, EO and IO and in length of the Linea Alba when performing the prone plank, bird dog, dead bug, lateral plank, glute bridge and hip extension.

2.2 Participants

The sample size was estimated using GPower statistical package (Faul et al., 2007) for an ANOVA with within-subjects design aiming for an effect size (f) of 0.40 (large effects), alfa of 0.05 and power of the test of 0.80 assuming a minimum of six measures (i.e. exercises) per session, leading to a total of eight participants needed, which we deemed small. Thirteen apparently healthy participants (6 females and 7 males) volunteered for the study, with a body mass of 80 ± 20.5 kg and stature of 174.8 ± 9 cm. Participants were recruited via university newsletter and advertisement placed in noticeboards at the university campus. Inclusion criteria required that participants would be free from any musculoskeletal injuries and have six months of experience in performing abdominal exercises as part of their exercise program (Häkkinen et al., 2000). This study was approved by the University Human Research Ethics Committee (HEC19040) and all participants provided informed consent prior to take part in the study.

2.3 Procedures

Participants attended to one exercise session in the Exercise Conditioning Laboratory between June and October 2019, where, after provision of informed consent to participate, anthropometric measures (i.e. body mass and standing height) were taken using a weighing scales (Model 762; Seca, Germany) and a portable stadiometer (Model 123; Seca, Germany). Baseline ultrasound images were collected whilst participants were on dorsal decubitus on a plinth (Beazell et al., 2011). Warm up was prescribed as walking on a treadmill for 8-min at 5 km/h, which was followed by a familiarisation with the exercises (i.e. prone plank, bird dog, dead bug, lateral plank, glute bridge and hip extension), as illustrated in Fig. 1.

alt-text: Fig. 1

Fig. 1

Illustration of the exercises performed in this study.

Once participants' technique was deemed appropriate, they performed each exercise, statically for 3–5s, in randomised order. The choice for a static pose rather than dynamic motion for all exercises was to allow for ultrasound images to be obtained. Each pose was held at the 'end' position of each exercise and a 2-min passive rest was enforced between each exercise. A standard 6 to 20-point rating of perceived exertion (RPE) scale (Borg, 1982) was used at the completion of each exercise to measure perceived exertion. The protocol was interrupted if the participant indicated a 'very hard' (17 points) an exertion at level in the 20-point scale.

Ultrasound B-mode images were obtained using an ultra-sonic diagnostic imaging system (DP-6900, Shenzhen Mindray Bio-Medical Electronics Co., Ltd, China) with a linear probe (55 mm, 75L53EA – 7.5 mHz, Shenzhen Mindray Bio-Medical Electronics Co., Ltd, China). Prior to scanning, the left antero-lateral portion of the abdominal wall was marked using a surgical marker pen in order to obtain a scan from the Linea Alba (i.e. 2 cm above the umbilicus) and the thickness of the TrA, EO and IO (i.e. mid-distance between the umbilicus and the midaxillary line). The probe was positioned transversely across the abdominal wall for both positions, as described in prior studies (Hides et al., 2007; Rasouli et al., 2011; Teyhen et al., 2005), and illustrated in Fig. 2. Care was taken to ensure that the probe was at the same position determined during baseline measures and all images were visually inspected prior to storage in the ultrasound system. Whenever the sonographer could not identify the Linea Alba or the TrA, EO and IO in an image, participants were required to repeat the exercise after resting. All images were captured as close as possible at the end of the exhalation, in order to minimise breathing effects on muscle thickness.

alt-text: Fig. 2

Fig. 2

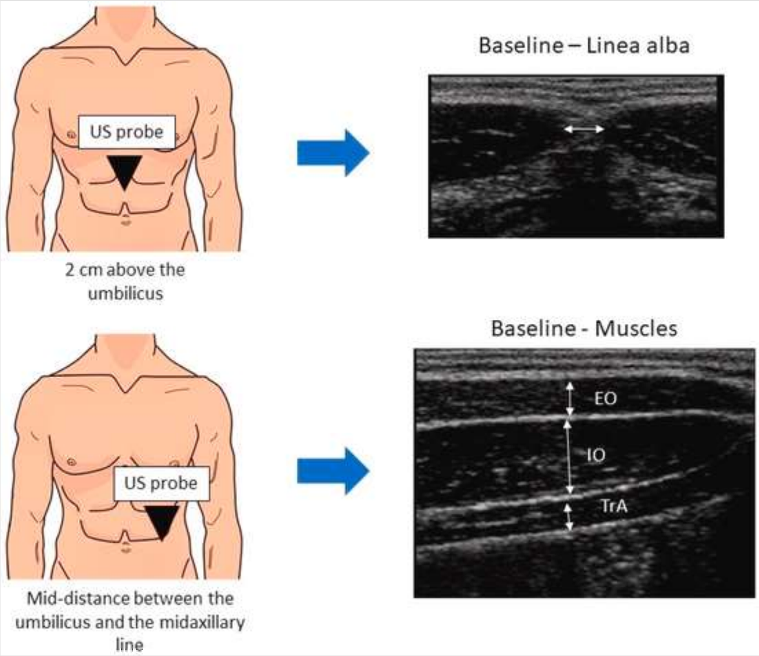
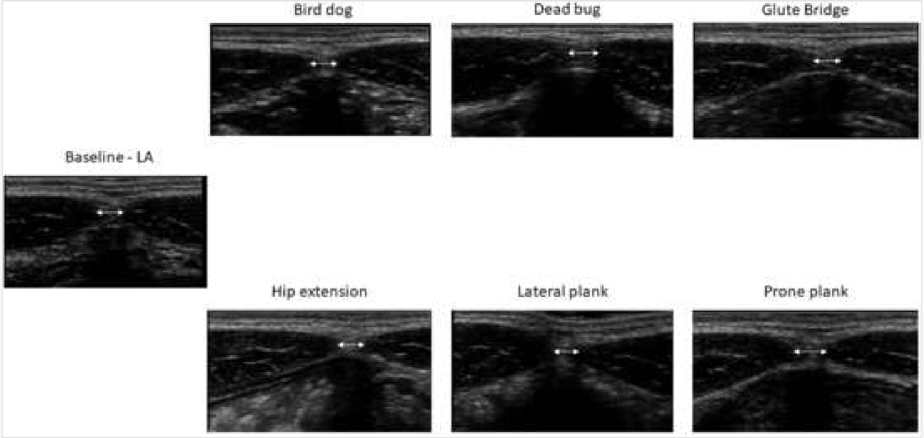


Illustration of the position of the ultrasound probe to scan the Linea Alba and to collect images from the TrA (transverse abdominis), EO (external oblique) and IO (internal oblique).

Images were analysed by a single trained investigator using ImageJ (v.1.52a, NIH, USA), where the Linea Alba was determined as the distance between the medial aponeuroses of the Rectus Abdominis muscles (see Fig. 3, Beer et al., 2009). In addition, thickness of TrA, EO and IO were determined as the inside edge of fascial bands (Rasouli et al., 2011), as shown in Fig. 4, with all measures conducted perpendicular to the muscle fascia. Measures were taken twice per image and the mean value was used for further analysis. Length of the Linea Alba and muscle thickness were normalised, for each exercise, by measures taken during baseline, in order to reduce between-participants variability in the data and to allow for the analysis of overall changes in the outcomes from exercises.

alt-text: Fig. 3

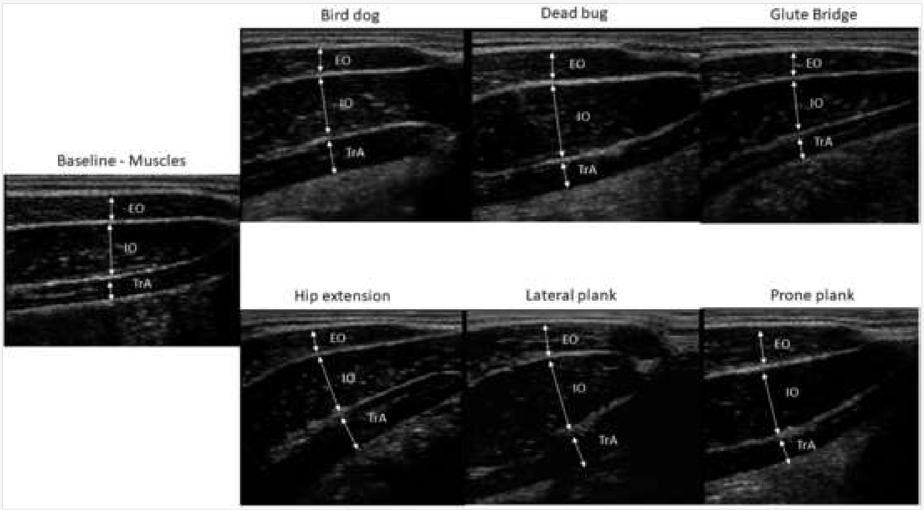
Fig. 3



Ensemble illustration of the measurement of the length of the Linea Alba at Baseline and for each exercise.

alt-text: Fig. 4

Fig. 4



Ensemble illustration of the measurement of the thickness of the TrA (transverse abdominis), EO (external oblique) and IO (internal oblique) at Baseline and for each exercise.

2.4 Statistical analysis

Statistical analysis was conducted and reported in accordance to SAMPL - guidelines for statistical reporting (http://www.equator-network.org/reporting-guidelines/sampl/). Shapiro-Wilk's tests were performed to assess normality of data and if data breached the assumption of normality, log-transformations were performed prior to further statistical analyses. After that, a repeated measures ANOVAs were used to compare differences between exercises for the length of the Linea Alba and for the thickness of the TrA, EO and IO. The sum of the thickness of the muscles was also compared as a measure of global changes in muscle engagement between exercises. Significant main effects were followed up by Tukey post hoc analyses. Statistical analyses were performed in JASP (https://jasp-stats.org/) and in Microsoft Excel, and all data were expressed as mean ± SD with statistical significance was set at $p < 0.05$. Confidence intervals (CI-95%) were calculated in order to illustrate changes in Linea Alba and muscle thickness from performing the exercises in relation to the baseline measures. Cohen effect sizes (d) were calculated and considered large when $d > 0.80$.

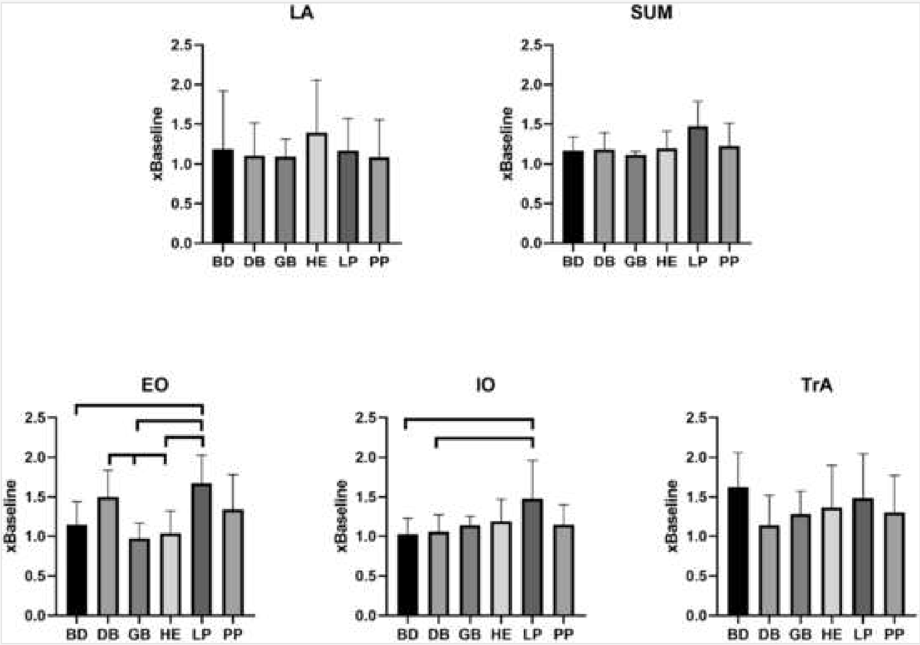
3 Results

Exercises led to an overall increase in length for the Linea Alba in relation to the baseline measures (CI-95% = 106–129% of baseline). Likewise, the thickness of the TrA (CI-95% = 126–146% of baseline), EO (CI-95% = 118–136% of baseline), IO (CI-95% = 110–124% of baseline) and the sum of muscle thickness (CI-95% = 117–128% of baseline) also increased in relation to the baseline.

Group results for the length of the Linea Alba and muscle thickness are illustrated in Fig. 5. Linea Alba length (p = 0.77) and TrA thickness (p = 0.23) were not different between exercises. EO thickness was larger for the lateral plank compared to the bird dog (p = 0.01, d = 1.73), glute bridge (p < 0.01, d = 2.64), and hip extension (p < 0.01, d = 1.89). The dead bug was also larger in comparison to the glute bridge (p < 0.01, d = 2.05) and to the hip extension (p = 0.01, d = 1.45). For the IO thickness, the lateral plank was larger than the bird dog (p = 0.03, d = 1.21) and the dead bug (p = 0.04, d = 1.12). For the sum of thickness from the three muscles, no effect from exercise was detected (p = 0.05) but large effect sizes were observed for the lateral plank in relation to the prone plank (d = 0.82), glute bridge (d = 1.63), dead bug (d = 1.07), hip extension (d = 0.97) and the bird dog (d = 1.17).

alt-text: Fig. 5

Fig. 5



Mean + SD of Linea Alba length thickness of the TrA (transverse abdominis), EO (external oblique), IO (internal oblique) and sum of muscles (SUM) for each exercise (BD – Bird Dog, DB – Dead Bug, GB – Glute Bridge, HE – Hip Extension, LP – Lateral Plank and PP – Prone Plank). Data is presented as proportion of Baseline measures.

4 Discussion

This study demonstrated increases in length for the Linea Alba during exercise in relation to rest and that some exercises (e.g. lateral plank and dead bug) resulted in greater thickness (i.e. larger engagement) for the EO and IO. However, no difference was observed between exercises for the length of the Linea Alba or for the thickness of the TrA or for the sum of muscle thickness. These results are new because no prior study has assessed changes in Linea Alba length during core-orientated exercises, which is important to assess the likelihood of increases in strain in the Linea Alba. In addition, limited evidence has been available demonstrating that TrA engagement was not different between traditional core exercises (Martuscello et al., 2013).

Recommendations for conservative treatment of the Diastasis Recti Abdominis usually involve aiming to chronically reduce the length of the Linea Alba via strengthening the TrA and/or using abdominal splinting (Michalska et al., 2018). In addition, it has been noted that, exercises programs targeting the TrA showed potential to chronically reduce the length of the Linea Alba (Benjamin et al., 2014). Moreover, prior studies demonstrated that, when the TrA is pre-activated, there is an acute increase in the length of the Linea Alba in comparison to less TrA pre-activation (Lee & Hodges, 2015, 2017). These findings align with acute responses from the current study because all exercises led to an increase in length for the Linea Alba with concomitant engagement of the TrA. This means that, acutely, it would be beneficial to stretch the Linea Alba whilst exercising in order to apply stress and strain in the tissue, which refutes the benefits from using splints to reduce the length of the Linea Alba whilst exercising (Michalska et al., 2018). As a tendon-like structure, the Linea Alba is likely to respond chronically, more effectively, if stress and strain are applied concomitantly through exercise (Geremia et al., 2018). Therefore, aiming to engage the TrA prior to performing exercise seems to be effective to provide strain and stress to the Linea Alba. Further studies are required though to assess chronic changes from performing core-orientated exercise in the length of the Linea Alba given a prior study only monitored chronic changes from performing a drawing-in manoeuvre (Mota et al., 2015).

Engagement of TrA was not different between exercises, which supports evidence from a systematic review (Martuscello et al., 2013). This finding shows that, for the assessed exercises, TrA does not seem to differ in terms of engagement, with other muscles having a distinct contribution. For example, EO and IO engaged further in the lateral plank compared to the bird dog and to the dead bug (IO only), which could be related to the role of these muscles in avoiding a lateral flexion of the spine (Lehman et al., 2005; Willardson et al., 2010). Larger engagement for the EO in the lateral plank in relation to the glute bridge and to the hip extension were expected as these exercises are more suited for engaging the Longissimus Thoracis and the Lumbar Multifidus Muscles (Ekstrom et al., 2007). Likewise, the dead bug requires engagement of abdominal muscles (i.e. EO) in order to counteract the torque from the lower limb that has moved towards extension. Interestingly, the sum of muscle thickness was not different between exercises, which seems to suggest that TrA, EO and IO may have different roles in the assessed exercises. Further studies are beneficial to assess longer term adaptations from each muscle to each type of exercise, which could illustrate the best possible exercises to train each individual muscle.

This study was limited to a certain extent. Participants from this study had a minimum of six months of experience in performing abdominal exercises as part of the exercise program, but they were not trained in a specific exercise from this study. Therefore, future studies could compare the responses from the Linea Alba and muscle engagement in participants trained in the exercises of interest. In addition, participants from this study were not affected by Diastasis Recti Abdominis, which may confound the applications of these findings to a clinical population. With this in mind, future studies should compare a range of core-orientated exercises in postpartum women, extending from a prior study (Mota et al., 2015).

5 Conclusions

In summary, the Linea Alba was stretched during all exercises and exercises such as the lateral plank and the dead bug resulted in greater engagement of the EO and IO. No difference was observed between exercises for the length of the Linea Alba or for the thickness of the TrA, which suggests that this muscle is similarly engaged in the assessed exercises, leading to a consistent stretch for the Linea Alba. Q3

CRediT authorship contribution statement

Rodrigo Rico Bini: Conceptualization, Methodology, Investigation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Alice Flores Bini:** Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

Authors declare no conflict of interested related to the content of this paper.

Acknowledgements

The author would like to thank Miles Green, Shianne Hammond, Thelma Patterson and Mathew Goodwin for support during data collection and all cyclists who volunteered for this study. We also thank David Brereton for his help in the analysis of data.

References

Axer, H., DGv, Keyserlingk, Prescher, A., 2001. Collagen fibers in linea alba and rectus sheaths: I. General scheme and morphological aspects. J. Surg. Res. 96, 127–134.

Beazell, J.R., Grindstaff, T.L., Hart, J.M., Magrum, E.M., Cullaty, M., Shen, F.H., 2011. Changes in lateral abdominal muscle thickness during an abdominal drawing-in maneuver in individuals with and without low back pain. Res. Sports Med. 19, 271–282.

Beer, G.M., Schuster, A., Seifert, B., Manestar, M., Mihic-Probst, D., Weber, S.A., 2009. The normal width of the linea alba in nulliparous women. Clin. Anat. 22, 706–711.

Benjamin, D.R., van de Water, A.T.M., Peiris, C.L., 2014. Effects of exercise on diastasis of the rectus abdominis muscle in the antenatal and postnatal periods: a systematic review. Physiotherapy 100, 1–8.

Borg, G.A.V., 1982. Psychophysical bases of perceived exertion. Med. Sci. Sports Exerc. 14, 377–381.

Carpes, F.P., Reinehr, F.B., Mota, C.B., 2008. Effects of a program for trunk strength and stability on pain, low back and pelvis kinematics, and body balance: a pilot study. J. Bodyw. Mov. Ther. 12, 22–30.

Chang, W.-D., Lin, H.-Y., Lai, P.-T., 2015. Core strength training for patients with chronic low back pain. J. Phys. Ther. Sci. 27, 619–622.

Coldron, Y., Stokes, M.J., Newham, D.J., Cook, K., 2008. Postpartum characteristics of rectus abdominis on ultrasound imaging. Man. Ther. 13, 112–121.

Cresswell, A.G., Grundstrom, H., Thorstensson, A., 1992. Observations on intra-abdominal pressure and patterns of abdominal intra-muscular activity in man. Acta Physiol. Scand. 144, 409–418.

Ekstrom, R.A., Donatelli, R.A., Carp, K.C., 2007. Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. J. Orthop. Sports Phys. Ther. 37, 754–762.

Faries, M.D., Greenwood, M., 2007. Core training: stabilizing the confusion. Strength Condit. J. 29, 10.

Faul, F., Erdfelder, E., Lang, A.-G., Buchner, A., 2007. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav. Res. Methods 39, 175–191.

França, F.R., Burke, T.N., Hanada, E.S., Marques, A.P., 2010. Segmental stabilization and muscular strengthening in chronic low back pain: a comparative study. Clinics 65, 1013–1017.

Fredericson, M., Moore, T., 2005. Muscular balance, core stability, and injury prevention for middle- and long-distance runners. Physical Medicine and Rehabilitation Clinics 16, 669–689.

Geremia, J.M., Baroni, B.M., Bobbert, M.F., Bini, R.R., Lanferdini, F.J., Vaz, M.A., 2018. Effects of high loading by eccentric triceps surae training on Achilles tendon properties in humans. Eur. J. Appl. Physiol. 118, 1725–1736.

Häkkinen, K., Alen, M., Kallinen, M., Newton, R.U., Kraemer, W.J., 2000. Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people. Eur. J. Appl. Physiol. 83, 51–62.

Hides, J.A., Miokovic, T., Belavý, D.L., Stanton, W.R., Richardson, C.A., 2007. Ultrasound imaging assessment of abdominal muscle function during drawing-in of the abdominal wall: an intrarater reliability study. J. Orthop. Sports Phys. Ther. 37, 480–486.

Hodges, P.W., 1999. Is there a role for transversus abdominis in lumbo-pelvic stability? Man. Ther. 4, 74–86.

Hodges, P.W., 2003. Core stability exercise in chronic low back pain. Orthop. Clin. N. Am. 34, 245–254.

Hosseinifar, M., Akbari, M., Behtash, H., Amiri, M., Sarrafzadeh, J., 2013. The effects of stabilization and mckenzie exercises on transverse abdominis and Multifidus muscle thickness, pain, and disability: a randomized controlled trial in NonSpecific chronic low back pain. J. Phys. Ther. Sci. 25, 1541–1545.

Huxel Bliven, K.C., Anderson, B.E., 2013. Core stability training for injury prevention. Sports health 5, 514–522.

Lee, D., Hodges, P., 2015. Behaviour of the linea alba during a curl-up task in diastasis rectus abdominis: a new interpretation with clinical implications. Physiotherapy 101, e580–e581.

Lee, D., Hodges, P.W., 2017. Diastasis rectus abdominis – should we open or close the gap? Musculoskeletal Science and Practice 28, e16.

Lehman, G.J., Hoda, W., Oliver, S., 2005. Trunk muscle activity during bridging exercises on and off a Swiss ball. Chiropr. Osteopathy 13, 14 14.

Martuscello, J.M., Nuzzo, J.L., Ashley, C.D., Campbell, B.I., Orriola, J.J., Mayer, J.M., 2013. Systematic review of core muscle activity during physical fitness exercises. J. Strength Condit Res. 27.

McGill, S.M., 1998. Low back exercises: evidence for improving exercise regimens. Phys. Ther. 78, 754–765.

Michalska, A., Rokita, W., Wolder, D., Pogorzelska, J., Kaczmarczyk, K., 2018. Diastasis recti abdominis — a review of treatment methods. Ginekol. Pol. 89, 97–101.

Miller, E.R., Schenk, R.J., Karnes, J.L., Rousselle, J.G., 2005. A comparison of the McKenzie approach to a specific spine stabilization program for chronic low back pain. J. Man. Manip. Ther. 13, 103–112.

Moesbergen, T., Law, A., Roake, J., Lewis, D.R., 2009. Diastasis recti and abdominal aortic aneurysm. Vascular 17, 325–329.

Mota, P., Pascoal, A.G., Carita, A.I., Bø, K., 2015. The immediate effects on inter-rectus distance of abdominal crunch and drawing-in exercises during pregnancy and the postpartum period. J. Orthop. Sports Phys. Ther. 45, 781–788.

Parker, M.A., Millar, L.A., Dugan, S.A., 2009. Diastasis rectus abdominis and lumbo-pelvic pain and dysfunction-are they related? Journal of Women's Health Physical Therapy 33.

Rasouli, O., Arab, A.M., Amiri, M., Jaberzadeh, S., 2011. Ultrasound measurement of deep abdominal muscle activity in sitting positions with different stability levels in subjects with and without chronic low back pain. Man. Ther. 16, 388–393.

ShahAli, S., Arab, A.M., Ebrahimi, E., ShahAli, S., Rahmani, N., Negahban, H., Kazemnejad, A., Bahmani, A., 2019. Ultrasound measurement of abdominal muscles during clinical isometric endurance tests in women with and without low back pain. Physiother. Theory Pract. 35, 130–138.

Teyhen, D.S., Miltenberger, C.E., Deiters, H.M., Del Toro, Y.M., Pulliam, J.N., Childs, J.D., Boyles, R.E., Flynn, T.W., 2005. The use of ultrasound imaging of the abdominal drawing-in maneuver in subjects with low back pain. J. Orthop. Sports Phys. Ther. 35, 346–355.

Willardson, J.M., Behm, D.G., Huang, S.Y., Rehg, M.D., Kattenbraker, M.S., Fontana, F.E., 2010. A comparison of trunk muscle activation: ab circle vs. Traditional modalities. J. Strength Condit Res. 24.

Queries and Answers