Med Ultrason 2020, Vol. 22, no. 4, 430-437
DOI: 10.11152/mu-2526

Assessment of Rectus Abdominis muscle thickness during isometric trunk and leg lifting exercises using extended field of view (EFOV) ultrasound

Konstantinos Dafkou[1], Eleftherios Kellis[1], Athanasios Ellinoudis[1], Chrysostomos Sahinis[1], Nikiforos Galanis[2]

[1]Laboratory of Neuromechanics, Department of Physical Education and Sport Sciences at Serres, [2]Medical School, Aristotle University of Thessaloniki, Greece

Abstract

Aim: The purpose of the present study was to establish which type of exercise is optimal for Rectus Abdominis (RA) muscle, by measuring thickness and length changes using the extended field of view ultrasonography (EFOV US) during different conditions. The second purpose was to estimate the reliability of EFOV US as a muscle morphology assessment tool. **Material and methods:** Segmental muscle thickness and length of 11 young healthy adults was assessed during 1) rest and isometric 2) trunk lifting, 3) leg lifting and 4) combined trunk and leg lifting exercises with the use of EFOV US. **Results:** RA muscle thickness was significantly greater during exercises compared to rest ($p<0.05$). It was also observed that proximal and proximal-middle segments showed significantly less thickness and length compared to distal-middle and distal segments ($p<0.05$). Even though no differences in thickness were observed between the exercises, leg lifting and combined trunk and leg lifting exercises affected more the distal segment of RA muscle ($p<0.05$). Moreover, no significant differences in length between exercises was found ($p>0.05$). Further, EFOV US displayed excellent reliability as the ICC values ranged from 0.82 to 0.97. **Conclusions:** According to our observations it seems that exercises that induce lifting of the legs might be more effective for the distal parts of RA muscle. EFOV appears to be a reliable diagnostic tool for measuring RA muscle thickness during rest and contracting states.

Keywords: abdominal muscle; muscle architecture; ultrasonography; panoramic images

Introduction

The main function of Rectus Abdominis (RA) is to flex the trunk when the lower extremities are fixed [1]. RA muscle's function also influences the pelvis and the hip [2] and it promotes trunk stabilization by counteracting trunk extension forces [3]. For this reason, the effectiveness of exercises for improving RA muscle function as part of a typical strength and conditioning program have been investigated [3–6].

RA muscle strengthening exercises come in different forms including trunk flexion ("trunk lift") [4,5,7–9] and hip flexion ("leg lift") [2,10,11] or both [3,12]. However, it is unclear which form of exercise is the most effective in recruiting abdominal musculature. Some studies have found greater electromyographic (EMG) activation of the RA during leg lifting compared to trunk lifting exercises [13] but others reported the opposite [9]. On the contrary, other studies have found that combined trunk and leg lifting exercises result in greater RA EMG activity [3,12,14], especially when exercises are performed against resistance provided by accessories (such as a "power wheel roll-out") [3] or when exercises are performed on an unstable surface (such as "Jacknife" and "Rollouts") [14].

Received 28.03.2020 Accepted 30.06.2020
Med Ultrason
2020, Vol. 22, No 4, 430-437

Corresponding author: Konstantinos Dafkou
Laboratory of Neuromechanics,
Aristotle University of Thessaloniki,
TEFAA Serres, 62100, Greece
E-mail: kdafkos@phed-sr.auth.gr
Tel: +30 6948667788

The RA muscle is separated vertically in two parts by the linea alba and longitudinally in three sections which are defined by corresponding transverse tendinous inscriptions (aka tendinous intersections) [15], forming a muscle with different segments on each side of the belly. The notion of selective activation of RA's segments is possible, since "different muscle portions can be innervated by different nerves as well as by a common nerve branch [16–19]" [20]. Hence, the differences in the recruitment between upper and lower RA muscle segments have been examined [3,7,14,20,21]. In particular, some studies have shown a greater EMG activation of the upper RA region during the trunk lift [14,20,21], Swiss ball curl-up [14] and ball rollout [14] exercises compared with the EMG activity recorded from the lower region of the RA. In contrast, upper region RA EMG activity was lower than the lower region during leg lifting [21] and jacknife exercise [14]. Others, however, reported no differences in EMG activity between upper and lower RA during the "crunch" (trunk lift) and reverse crunch (leg lift) exercises [3,5,22]. Hence, regional activation differences of the RA during typical abdominal exercises remain unclear.

Ultrasonography (US) is a safe, non-invasive and inexpensive method used for the quantification of muscle architecture. Considering that skeletal muscle architectural parameters (pennation angle, thickness, fascicle length) change during static and dynamic contractions [23], US technology can assist in the assessment of muscle behaviour during different tasks. Measures of abdominal muscles' thickness changes with US, correlates well with EMG activity of the muscle [23] and thus, can be used as a surrogate index of muscle activation. A few research studies have examined RA muscle atrophy and contraction intensity during exercise using US [5,6,24,25]. Kim et al [5] found that both trunk and leg lift significantly increased RA thickness compared to rest and concluded that both types of exercise are effective for activating this muscle. A limitation of US evaluation is that it permits observation of only a limited region of the muscle of interest and thus, long muscles like the RA, require multiple measurements in different segments. Extended field-of-view (EFOV) US overcomes this limitation as it allows the scanning of entire tissue areas within one continuous scan [26] with high reliability [27]. For the RA muscle, EFOV US can assist in visualizing the distance between tendinous inscriptions, thus proving an estimate of the amount of RA shortening from rest to contraction.

RA strengthening exercises are an integral part of most regular exercise programs. Therefore, understanding the differences in RA muscle function between various exercise types is worthwhile. While there are indications that trunk lifting and leg lifting exercises recruit the upper and lower part of the RA, respectively, more information on the potential differences in morphology in various compartments of the RA is essential. To our knowledge, no study has quantified RA muscle segmental thickness and length changes during isometric trunk flexion, hip flexion and combined trunk and hip flexion exercises using EFOV-US. Hence, the purpose of the present study was to investigate whether muscular thickness assessed in different RA regions differs between different exercises. We hypothesized that isometric trunk lifts would induce greater contraction thickness for the upper portions of RA, while isometric leg lifts would trigger more the lower RA segments.

Materials and methods

Experimental design

The experiment included the measurement of all the RA muscle segments across its length, after scanning longitudinally the muscle with an EFOV US probe, at rest and during three controlled isometric abdominal exercises: 1) trunk lift from the supine position (legs resting straight), 2) straight leg lift from the supine position and 3) combined trunk and leg lift. Isometric tasks were chosen in order to prevent body shape deformation, that would disturb a smooth scan with the US probe. Panoramic US images were acquired on the left side of the participants' RA muscle.

Participants

A total of 11 active young male adults (mean±standard deviation (SD): age: 21.6±2.41 years; mass 80±5.17 kg; height 182±7.21 cm) participated voluntarily in this study. They were all healthy individuals with no musculoskeletal pain or history of surgical treatment in the area of interest and they were asked to refrain from any vigorous exercise 24h prior to the tests. None of the participants were involved systematically in sports or training that requires asymmetric movements of the trunk (tennis, rowing) but had 4.1 (±1.5) years of previous training experience. The participants gave their informed written consent after information regarding the aim of the study, imaging procedure and safety of the US technology was given to them. The protocol was approved by the local University Ethics Committee.

Instrumentation

Panoramic US images of RA were obtained using a portable brightness mode (B-mode) ultrasound imaging device (GE Logiq e, USA) and a multifrequency linear-array probe (12 L-RS, 5–13 MHz, 40.0-mm field-of-view). GE e Logic Logic View software was used to produce panoramic images of each MTU in real time. The

US EFOV images were digitally stored and analyzed using ImageJ Software (Version 1.47v, National Institutes of Health Bethesda, MD, USA).

Procedure

Panoramic images of RA muscle were recorded in each of the four different conditions in a randomized order, with the participants lying supine on a physiotherapy bed: 1) rest, 2) isometric trunk lift, 3) isometric straight leg lift, 4) isometric combined trunk and leg lift. The participants were provided with standardized instructions regarding the duration and proper execution of the exercises. Enough time was given to the participants for familiarization with the tasks. In the Rest condition the participants were in supine position with their arms next to the body and legs straight. They were instructed to remain relaxed and avoid unnecessary movements. In the isometric trunk lift, the participants were instructed to attempt to "lift their upper body up" pushing with maximum effort against the resistance provided by a Velcro strap wrapped around their chest and secured on the bed. For the isometric straight leg lift, a Velcro strap was wrapped around their legs and secured on the bed. The participants were then instructed to "lift their legs up" pushing with maximum effort against the resistance provided by the strap. In the final exercise, the subjects performed a combined isometric trunk and leg lift, pushing with maximum effort against the resistance provided by two Velcro straps (fig 1). The straps were adjusted so that the tasks would induce a minor change in the angle of trunk and hip flexion, for scanning purposes. In each condition, the participants were instructed to hold their contraction for as long as it was required for the examiner to scan the entire muscle (approximately 10 sec). They were also instructed to exhale prior to contraction (respiratory muscles are relaxed) for consistency in the recordings.

Ultrasound measurements

The examiners calculated the distance between the xiphoid process to the pubic bone, where the RA muscle has its superior and inferior attachments and marked their position on the skin with a surgical marker. The distance between the two ends was measured using a measurement tape and provided the approximate total muscle length. Subsequently, a scanning longitudinal path for the US probe was marked on the skin by placing two adhesive tape slices (2.5 cm width) to the skin, 3 cm apart. The scanning path was created approximately 2 cm laterally to the linea alba, based on the ultrasound measurement of a previous applied protocol [6], where the RA muscle appeared the thickest. The placement of the tape created a path that the ultrasound probe could be guided through to obtain the panoramic image. In addition, two thin wires were tied around the participants' abdominal area, perpendicular to the scanning path, one above and one below the umbilical level. This was necessary in order to have two benchmarks in the US image and thus, any tendon lateral slides can be observed.

For the acquisition of the image, the US probe was slowly and continuously moved from the proximal

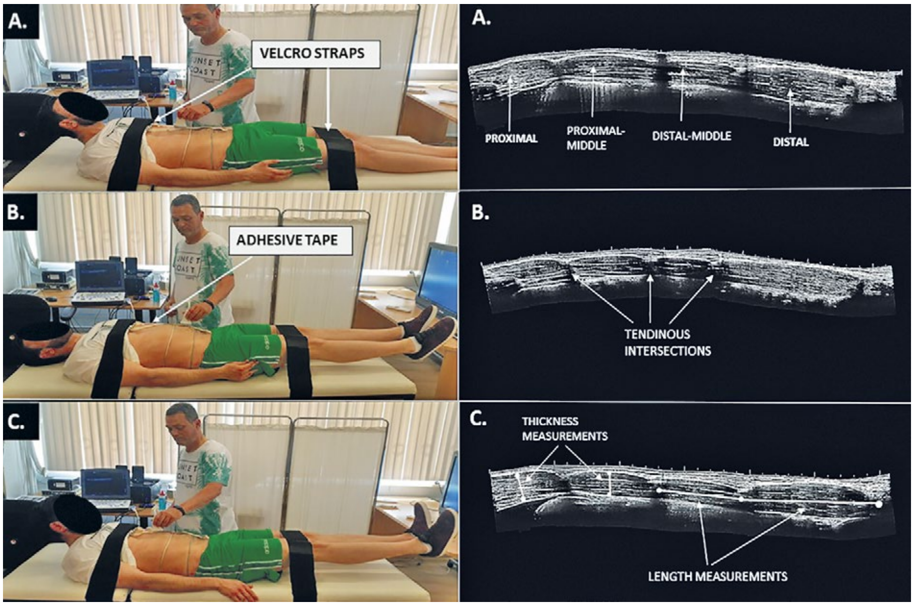

Fig 1. Illustration of the ultrasound measurement technique of the RA muscle during isometric A trunk lifting, B leg lifting and C combined trunk and leg lifting exercises. Thickness measurements were made between the superficial and deep borders of the RA muscle's segment (drawn with a line). Length measurements were made between two consecutive tendinous intersections (drawn with a line).

muscle section (closer to the rib cage) towards the distal part of the muscle (closer to the pubic bone), parallel to the linea alba. Great care was taken to ensure that consistent minimal pressure was applied with the probe to avoid muscle compression. Further, water-soluble transmission gel was applied liberally to the areas of imaging to ensure good sonic coupling between the transducer and the skin. Intra-rater reliability of EFOV measurements was examined across 2 repeated measurements of the same image in rest and all contracted conditions, which were taken with 2 minutes rest between trials.

Data analysis

Image visualization and measurements were conducted using ImageJ software (Version 1.47v, National Institutes of Health Bethesda, MD, USA). On each image, thickness and length of every RA muscle segment (the muscle portion between two consecutive tendinous intersections) across its length, as well as the total muscle length was measured. Thickness of each RA segment was measured as the distance between the superior and inferior hyperechoic muscle fascias, at the middle of the segment. Each segment length was assessed as the distance between two consecutive tendinous inscriptions as demonstrated in figure 1. Contraction thickness ratio for each segment was calculated by using the following equation: $\text{thickness}_{\text{contracted}} - \text{thickness}_{\text{rest}} / \text{thickness}_{\text{rest}}$

Statistical analysis

ICCs were calculated for the assessment of intra-examiner reliability between 2 measurements, for every segment of the muscle as well as for the total muscle length. An ICC value ≤0.50 was considered low, 0.50 to 0.75 moderate, ≥0.75 good and ≥0.90 excellent. Biases were also estimated by calculating the mean difference between measures; values closer to 0 indicated greater agreement and LOAs were calculated as the mean difference ± 2 × SD [28]. To assess measurement precision, the standard error of measurement (SEM) was calculated by using the following equation: $\mathrm{SEM} = \mathrm{SD} \times \sqrt{(1-\mathrm{ICC})}$.

The statistical package for the social sciences (SPSS) software version 25 was used to analyze the generated data. Two-way (4 X 4) analysis of variance (ANOVA) designs with repeated measures were applied to examine the differences in muscle thickness or muscle length between four conditions (rest, trunk lift, leg lift, combined) and four measurement locations (proximal, proximal-middle, distal-middle and distal). Differences in total muscle length between four testing conditions were examined using a one-way ANOVA model. Post-hoc Tukey tests were performed in order to investigate possible differences between pairs of means. The level of significance was set to a = 0.05.

Results

Reliability

Reliability results are presented in Table I for muscle thickness, in Table II for segment lengths and in Table III for total length. For thickness, the $ICC_{2,1}$ ranged from 0.82 to 0.97 for thickness measurements, the maximum SEM was 0.123 cm and Bias estimates ranged from -0.242 to 0.132 cm. For segment lengths, the ICCs ranged from 0.86 to 0.99, maximum SEM was 0.522 cm and bias ranged from -0.549 to 0.892 cm. For total length measurements, the ICC ranged between 0.82 and 0.94, the maximum SEM was 0.717 cm and the bias ranged from -0.465 to 0.353 cm.

Muscle thickness

Mean (± SD) muscle thickness in each condition are presented in Table I and figure 2 and represent pooled values from all measures in the corresponding condition. The ANOVA showed a statistically significant Condition by Segment interaction effect on muscle thickness ($F_{9.90}$=2.63, $p<0.05$). Post-hoc analysis showed that muscle thickness was significantly lower at rest compared with all exercise conditions ($p<0.05$). However, no differences in thickness between exercises was found ($p>0.05$). Further, proximal and proximal-middle segments showed less thickness than distal-middle and distal segments in all testing conditions ($p<0.05$). In addition, distal-middle segment thickness was significantly lower compared to distal segment thickness during leg lifting and combined trunk and leg lifting exercises ($p<0.05$).

Segment length

Mean (±SD) segment lengths in each condition for various sections are shown in Table II and figure 3. The ANOVA showed a non-statistically significant Condition by Segment effect on muscle length ($F_{9.90}$=1.05, $p>0.05$).

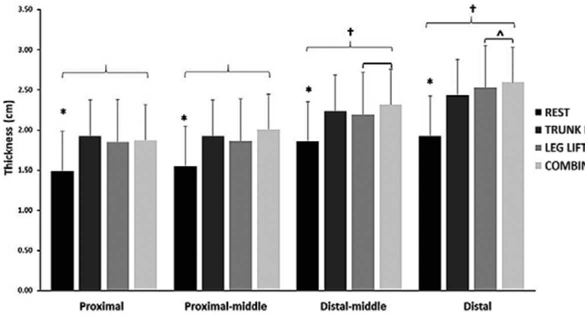

Fig 2. Mean group values of the thickness of rectus abdominis (RA) muscle's segments in each exercise condition (error bars indicate standard deviation). *significantly different compared with exercises, † significantly different compared with proximal and proximal-middle segment values, ^ significantly different compared with distal-middle segment values, $p<0.05$

No significant differences in length between exercises ($F_{3.30}$=0.67, p<0.05) was found. However, there was a significant main effect of Segment on length values ($F_{3.30}$=42.45, p<0.05). Post-hoc analysis indicated that the lengths of proximal and proximal-middle segments, collapsed across exercises, were significantly lower compared to distal-middle and distal segments (p<0.05). Further, distal-middle segment length was significantly lower compared to the distal segment length (p<0.05). Total muscle length values are presented in Table III. The ANOVA showed a non-statistically significant difference between exercise conditions (p<0.05).

Table I. Reliability values of each condition for the proximal, proximal-middle, distal-middle and distal segment thickness across the Rectus abdominis muscle

	Test (cm)	**R-test (cm)**	**$ICC_{2,1}$**	**SEM**	**Bias ± Lower LoA**	**Upper LoA**
Proximal Segment						
Rest	1.48 ± 0.25	1.65 ± 0.34	0.87	0.081	-0.076 ± -0.237	0.085
Trunk lift	1.92 ± 0.51	2.06 ± 0.48	0.82	0.123	-0.058 ± -0.423	0.307
Leg lift	1.84 ± 0.49	1.94 ± 0.65	0.93	0.019	0.132 ± 0.040	0.223
Combined	1.87 ± 0.42	2.18 ± 0.41	0.82	0.044	-0.212 ± -0.342	-0.081
Proximal-Middle Segment						
Rest	1.54 ± 0.43	1.79 ± 0.71	0.87	0.063	-0.078 ± -0.297	0.141
Trunk lift	1.92 ± 0.48	2.07 ± 0.35	0.90	0.051	-0.096 ± -0.306	0.114
Leg lift	1.86 ± 0.51	1.98 ± 0.55	0.96	0.034	-0.048 ± -0.284	0.188
Combined	2.00 ± 0.47	1.98 ± 0.39	0.89	0.119	-0.066 ± -0.532	0.400
Distal-Middle Segment						
Rest	1.85 ± 0.53	2.03 ± 0.69	0.88	0.082	-0.076 ± -0.381	0.229
Trunk lift	2.23 ± 0.58	2.26 ± 0.59	0.91	0.076	-0.008 ± -0.336	0.320
Leg lift	2.19 ± 0.61	2.24 ± 0.48	0.96	0.044	-0.056 ± -0.330	0.218
Combined	2.31 ± 0.54	2.35 ± 0.53	0.93	0.096	-0.042 ± -0.500	0.416
Distal Segment						
Rest	1.92 ± 0.30	2.03 ± 0.29	0.96	0.020	-0.026 ± -0.098	0.046
Trunk lift	2.43 ± 0.54	2.34 ± 0.43	0.97	0.019	-0.224 ± -0.375	-0.072
Leg lift	2.52 ± 0.48	2.37 ± 0.50	0.95	0.042	-0.080 ± -0.330	0.170
Combined	2.59 ± 0.52	2.43 ± 0.33	0.89	0.089	-0.168 ± -0.514	0.178

Measures of reliability: ICC: Intraclass Correlation Coefficient, SEM = standard error of measurement, Bias ± LoA = 95% Limits of agreement.

Table II. Reliability values of each condition for the proximal, proximal-middle, distal-middle and distal segment length across the Rectus abdominis muscle

	Test (cm)	**R-test (cm)**	**$ICC_{2,1}$**	**SEM**	**Bias ± Lower LoA**	**Upper LoA**
Proximal Segment						
Rest	5.42 ± 1.64	5.41 ± 1.43	0.96	0.117	0.004 ± -0.417	0.425
Trunk lift	5.61 ± 1.83	5.73 ± 2.06	0.96	0.138	-0.119 ± -0.613	0.375
Leg lift	6.24 ± 1.97	6.23 ± 1.86	0.95	0.185	0.009 ± -0.584	0.602
Combined	5.34 ± 1.60	5.81 ± 1.62	0.88	0.356	-0.468 ± -1.205	0.269
Proximal-Middle Segment						
Rest	6.53 ± 2.03	7.08 ± 2.38	0.89	0.449	-0.549 ± -1.517	0.419
Trunk lift	6.21 ± 1.43	6.70 ± 1.93	0.95	0.153	-0.486 ± -0.977	0.005
Leg lift	6.17 ± 1.18	5.90 ± 0.90	0.89	0.219	0.271 ± -0.203	0.745
Combined	6.18 ± 2.18	5.91 ± 1.39	0.86	0.469	0.278 ± -0.620	1.176
Distal-Middle Segment						
Rest	10.48 ± 5.05	10.70 ± 5.41	0.98	0.161	-0.220 ± -1.034	0.594
Trunk lift	10.33 ± 5.20	9.76 ± 5.09	0.99	0.094	0.564 ± -0.112	1.240
Leg lift	11.05 ± 5.11	10.61 ± 5.13	0.98	0.179	0.437 ± -0.407	1.344
Combined	11.19 ± 6.00	10.96 ± 5.57	0.98	0.182	0.232 ± -0.693	1.157
Distal Segment						
Rest	15.74 ± 3.10	14.95 ± 2.91	0.97	0.173	0.791 ± 0.074	1.507
Trunk lift	15.72 ± 2.96	14.83 ± 2.09	0.89	0.522	0.892 ± -0.234	2.018
Leg lift	15.19 ± 3.35	15.11 ± 2.52	0.95	0.290	0.081 ± -0.849	1.011
Combined	15.68 ± 3.39	15.55 ± 3.13	0.94	0.355	0.127 ± -0.911	1.165

Measures of reliability: ICC: Intraclass Correlation Coefficient, SEM = standard error of measurement, Bias ± LoA = 95% Limits of agreement.

Table III. Reliability values of each condition for the Rectus Abdominis muscle total length

Total Length	Test (cm)	R-test (cm)	$ICC_{2,1}$	SEM	Bias ± Lower LoA	Upper LoA
Rest	29.25 ± 2.34	29.71 ± 2.05	0.82	0.717	-0.46 ± -1.674	0.744
Trunk lift	29.31 ± 1.33	29.31 ± 1.56	0.89	0.294	-0.003 ± -0.637	0.631
Leg lift	29.71 ± 1.89	29.51 ± 1.78	0.93	0.233	0.203 ± -0.427	0.833
Combined	29.14 ± 2.72	29.21 ± 2.52	0.94	0.297	-0.071 ± -0.940	0.798

Measures of reliability: ICC: Intraclass Correlation Coefficient, SEM = standard error of measurement, Bias ± LoA = 95% Limits of agreement.

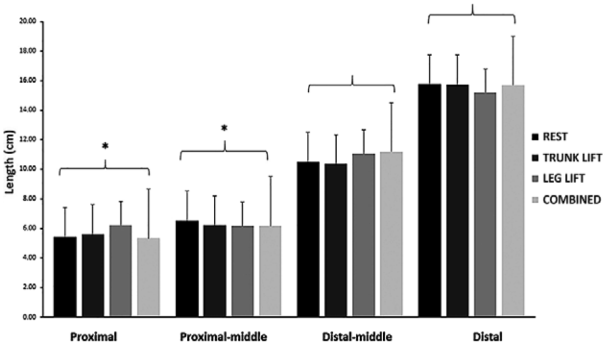

Fig 3. Mean group values of the length of rectus abdominis (RA) muscle's segments in each exercise condition (error bars indicate standard deviation). *significantly different compared with distal and distal-middle segment values, p<0.05

Discussion

The main findings of this study were that: a) RA muscle thickness increased during all three exercises; b) proximal and proximal-middle segments were lower in both thickness and length compared to distal-middle and distal segments; c) distal thickness increased more compared to distal-middle thickness during the isometric leg lift and combined trunk and leg lift; and d) EFOV assessment of RA thickness and length at rest and during contraction displayed high reliability in all muscle segments. To our knowledge, this is the first study which examined all RA segment thickness and lengths using EFOV-US.

The results of this study indicated a significant increase in thickness when the participants performed each of three isometric abdominal exercises compared to rest. However, as we did not observe any differences in thickness amongst the three exercises, we cannot safely state which exercise would be more effective for inducing a greater RA muscle contraction thickness. This is in line with the findings of Kim et al [5] who also did not observe differences in RA thickness between curl-up and leg raises. Results on EMG differences between these particular trunk exercises are conflicting as some studies [3,12,14] found that combined trunk and leg lifting exercises display greater EMG activation of RA than leg lift while others reported greater RA activation either during trunk lift [9] or during leg lift [13]. Comparisons with our findings is difficult as these studies [3,13,14] used EMG during dynamic movements as opposed to US thickness during isometric efforts implemented in this study. Considering that dynamic contractions have unique activation patterns [29], different observations are possible.

Muscle thickness increased from rest to exercise for all segments of the RA. Nevertheless, it was observed that distal thickness showed a greater increase compared to distal-middle thickness during leg lifting and combined trunk and leg lifting exercises. This partly confirms our hypothesis, suggesting a greater relative thickness response of the most distal parts of the RA during leg lift. These findings are in contrast to previous studies [3,5,22] which did not observe specific differences in exercise by region but they are line with others which reported greater EMG activation of upper RA portions during trunk curl-up [14,20,21] and greater activation of lower RA portions during leg raises [21]. There are various factors that may explain the differences in findings between the studies. First, as already mentioned, some studies implemented EMG as opposed to US used in our study and Kim et al [5]. Second, there are different definitions of "upper" and "lower' RA parts by different studies. Some research studies defined the upper RA in the midway between the sternum and the umbilicus and the lower part in the midway between the umbilicus and the pubis [3,7]. Other studies set the upper and lower RA 3 cm vertically up and down from the umbilicus, respectively [5] while other investigators took measurements from the second portion [20] or the midpoint between portions [21] below and above the umbilical level. Third, in some studies exercises were performed at low intensity [21] or with active movement [9,14] which is different to maximum isometric contractions monitored in this study. Finally, another factor that could affect comparisons between studies is the angle of trunk and hip flexion at which the measurements were taken. We measured the thickness of the RA muscle during trunk and leg lifting exercises at very low angles of flexion, no more than10° for trunk lift and for leg lift, which is lower compared to other studies [5,12,30]. The reason for this specific configuration was that in a larger angle, at least for the distal segments, the US probe would not have scanned smoothly near the pubic area. In contrast, Kim et al [5] reported that the most effective exercise angles for RA strengthening are 60° for trunk raises and 90° for leg raises, since these were the angles they observed the greatest muscle thickness. Using EMG, Yoo et al [12] reported the highest activation of RA muscle during a combined trunk curl is observed at an angle of 30° while the corresponding angle during a leg raise is 60°. However, in a recent study, curl-up exercise (20°) elicited higher RA activity compared with sit-up exercises (45°, 90°) [22].

As far as the length measurements is concerned, our results showed a lower proximal and proximal-middle segments length in comparison with distal and distal-middle segments (fig 3) which is in agreement with previous findings [25]. Maybe, the distal parts of the muscle are enlarged in order to sustain more mechanical load and possible injuries [1]. In addition, alterations in segmental and total muscle length during exercises, as a result of contraction, did not occur in our study. One explanation for this observation is that the RA contraction was isometric. Hence, even though muscle thickness increased due to contraction and one would expect muscle shortening, the length remained unchanged, possibly from passive components stretching.

Intra-examiner comparisons of RA muscle thickness, segment and total length showed excellent reliability. To our knowledge, this is the first study to examine the reliability of EFOV US in the assessment of RA thickness and length. Tanaka et al [27] reported excellent reliability in measuring the RA cross-sectional area (ICC values ranged from 0.944 to 0.958) and echo intensity (0.851 to 0.945) using EFOV US. Further, Keshwani et al [31] examined the inter recti distance (IRD) of RA in postpartum women and found that images acquired using EFOV techniques were highly correlated with those acquired using conventional imaging (r>0.95, p<0.001). In the latter study, the SEM of each EFOV technique was 0.170 - 0.180 cm. Moreover, the test-retest reliability of all techniques was excellent ($ICC_{3,1}$>0.90). Consequently, based on our results EFOV US is considered a reliable tool for the assessment of RA muscle thickness and length during rest and contracting states in young active adults. However, it should be stated, even though we did not assess the body fat percentage, that our participants were lean with low levels of subcutaneous fat and the US images obtained, were clearly visualized. It is possible, that in individuals with higher subcutaneous fat levels, data analysis might be more difficult.

Our study is not without any limitations. Simultaneous recording of muscle activation could provide additional useful information about recruitment strategies during various exercises, but in our study it was not feasible due to the use of US gel and continuous scanning of the whole muscle using EFOV US. Our participants were young healthy adults with a good level of conditioning. It is highly possible that results may differ if EFOV US is applied in populations with various pathologies. Moreover, our study involved monitoring of US thickness during isometric contractions; it is possible that during dynamic exercises or exercises from different joint configurations different results may be obtained. Further, the synchronized application of a hand dynamometer or similar device for the assessment of force would have ensured that maximum isometric efforts were made during the testing procedure. Finally, muscle thickness was obtained only for the left side. Hence, any asymmetries in muscle contraction between sides were not taken into consideration.

Conclusion

RA muscle thickness quantified using EFOV US increased during isometric trunk lifting, leg lifting and a combined trunk and leg lifting exercises. The magnitude of thickness increase did not differ between exercise conditions. However, it was observed that distal segments' thickness increased more during the leg lift and combined trunk and leg lift, compared to the distal segments' thickness. This implies that leg raising abdominal exercises might be more appropriate when target in training the lower regions of RA muscle, as these exercises elicited a higher contraction thickness for the distal segments due to possible higher stress for this region. Moreover, EFOV US appears to be a reliable method for the assessment of RA muscle thickness and length and it can be used for the detection of regional atrophy and contraction intensity of RA muscle.

Acknowledgements: The authors would like to thank all the students who volunteered to participate in this research study.

Conflict of interest: none

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