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Original Research

Lumbar Multifidus Muscle Thickness During Graded Quadruped and Prone Exercises

KONSTANTINOS DAFKOU†1, ELEFTHERIOS KELLIS‡1, ATHANASIOS ELLINOUDIS‡1, and CHRYSOSTOMOS SAHINIS†1

[1]Laboratory of Neuromechanics, Department of Physical Education and Sport Sciences at Serres, Aristotle University of Thessaloniki, GRC

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 14(7): 101-112, 2021. Exercises for lumbar multifidus (LM) muscle are important for injury and low back pain prevention and treatment. This study examined the differences in LM contraction thickness between variations of the superman and bird dog exercises. Twenty-one recreational athletes performed the superman exercise from the prone position with the following grading: rest, right upper extremity lift (RU), right lower extremity (RL) and upper and lower extremities lift (UL). They also performed the following bird dog variations from the quadruped position: rest, RU, RL and left upper - right lower extremity lift (LURL). LM muscle thickness of both sides was recorded using two ultrasonography (US) devices. LM thickness during superman-UL, was significantly greater compared with the other exercises and significantly lower during upper extremity exercises compared with lower extremity exercises ($p < 0.05$). No significant differences in LM thickness between sides was found ($p > 0.05$). The US measurements of LM thickness displayed good to excellent intrarrater reliability for both muscle sides. It appears that superman-UL is the most effective exercise for a greater contraction thickness of LM. Further, in order to progressively increase LM muscle thickness, upper extremity tasks should be performed prior to lower extremity tasks and combined upper and lower lifting tasks.

KEY WORDS: Trunk stabilization; ultrasonography; rehabilitation

INTRODUCTION

Core stability exercises are an integral part of training programs (12, 28, 37) which are used for injury prevention (28, 34) or sport performance increase (28). Lumbar multifidus (LM) is a deep muscle of the spine and an important stabilizer of the trunk (1, 10, 26). When the LM muscle is well developed and functional it controls the magnitude of spinal motion and provides stiffness to maintain mechanical stability (1). On the other hand, atrophy in the LM muscle is closely related to chronic low back pain (8). However, due to the fact that this muscle is located in the deepest layers of the lumbar musculature, specific exercises should be performed for selective LM training. Therefore, exercises that selectively recruit the LM are considered effective for improving lumbar stabilization (12, 28, 33).

Exercises that increase LM activity can be performed from different body positions such as sitting, standing, prone, supine or quadruped (3, 4, 19, 38). Exercises from the quadruped and prone positions, implementing upper and lower extremities raises, such as the "bird dog" and the "superman", have been proposed as ideal for selective training of the LM muscle, without increasing lumbar spine stress (12, 13, 17, 27, 38). The superman exercise is performed from the prone position and involves simultaneous upper and lower extremities raises (13, 17, 23). The Bird dog exercise is performed from the quadruped position and it involves simultaneous raises of the contralateral upper and lower extremities (17, 27, 38). During the superman exercise the LM thickness shows an increase of 34% compared to rest (13) while bird dog exercises shows lower values (20-30%) (15, 16). This provides an indication that bird dog exercise provides a lower intensity training stimulus than the superman exercise. This is supported by electromyography (EMG) analysis (6) which has shown a greater activation of the superman exercise compared to the bird dog exercise. However, given the deep location of the LM, the use of surface EMG to monitor LM activation may be influenced by crosstalk from surrounding muscles (36). To our knowledge, ultrasound (US) contraction thickness has not been directly compared between those exercises.

Variation or grades of either Superman or Bird dog exercise include lifting of upper or lower extremities in various combinations. Grading these exercise variations can assist in setting exercise progression during the training period. Studies have shown (13, 17, 23) that the superman exercise performed with both upper and lower extremities lifted elicits greater thickness than that performed with either the upper or the lower extremity alone. Bird dog exercise with diagonal upper and lower extremity raises also shows greater thickness than upper or lower extremity lifts alone (27). Only two studies (6, 17) compared surface EMG patterns between various exercises (superman, bird dog, dead-bug, curl-up). Ekstrom et al. (6) found that superman lifting both upper and lower extremities was more effective in activating the LM muscle compared to only upper extremities or diagonal upper and lower extremities lifting during superman exercise. EMG studies (17, 38) reported that the bird dog exercise with diagonal upper and lower extremity lift shows higher EMG LM activation compared with the same exercise with lifting only the upper or lower extremity. However, Kim et al., (17) did not observe any differences in EMG between variations of superman exercise. Hence, the efficiency of variations of superman and bird-dog exercises to recruit the LM muscle, needs further investigation.

Asymmetries in LM muscle between the two sides of the body are often encountered and have been proposed as possible indicators for lumbar pathology (8, 30). Such asymmetries may appear even in healthy individuals and they may require specific training (8, 30). Research (27, 38) has shown that during leg raise from the quadruped position the ipsilateral side of LM EMG activity is greater than the contralateral side, while arm raises affect more the contralateral than the ipsilateral side. Masaki et al. (27) reported that shoulder and hip abduction from the quadruped position is more effective for activating the LM of the contralateral side rather than the same side. However, whether upper and lower extremity lifting from the prone or quadruped positions affect differently the contraction thickness of left and right LM muscle has not been examined.

To develop optimal training programs, it is essential to understand which exercises can selectively strengthen a specific muscle (35). Most studies implemented EMG for the assessment of LM muscle activation (19, 27, 31, 38). This technique displays some limitations such as the influence of crosstalk activity from adjacent muscles (35) and the inconvenience of using invasive needle electrodes (16, 35). US imaging offers a non-invasive evaluation of changes in LM thickness during exercise relative to rest ("contraction thickness ratio") (11, 16) which is strongly correlated with LM EMG activation (16, 18, 21). US thickness has also a linear relationship with cross sectional area determined using magnetic resonance imaging (MRI) (2). Further, US measurements display good to excellent interrater (intraclass correlation coefficient (ICC) > 0.75) and intra-rater reliability (ICC > 0.90) for both experienced and novice raters, during rest and contraction of the LM (5,15).

Understanding the influence of various tasks on LM thickness may assist in ranking exercises based on their intensity and hence, to set the exercise progression during a given intervention period. Further, identifying exercises that specifically target one side of the body over the other may be particularly useful when asymmetries in LM function between sides are detected. Therefore, the purpose of the present study was, first, to examine differences in LM thickness between superman and bird dog exercises, second, to compare LM thickness between different grades of the superman and bird dog exercises, and finally, to examine differences in LM thickness during exercise between the two sides of the body.

METHODS

The experimental protocol included the measurement of LM muscle thickness on left and right side simultaneously, using US technology, during eight different conditions. Four of these were performed from the prone position and included graded superman exercises : 1) rest , 2) right upper extremity (RU), 3) right lower extremity lift (RL), 4) upper and lower extremities lift (UL) and the remaining four were bird dog exercises after assuming quadruped position: 5) rest, 6) RU, 7) RL and 8) left upper and right lower extremities lift (LURL). Ten participants returned to the laboratory for a re-test measurement in a follow-up session 2 days later. Intra-rater reliability of US measurements was examined across the 2 repeated measures of all 8 conditions.

Participants
Twenty-one recreational athletes (mean ± standard deviation (SD): age: 21.5 ± 2.11 years; mass 81.4 ± 5.17 kg; height 181 ± 6.31 cm) participated in this study voluntarily. The participants were all healthy males, free from musculoskeletal injuries and they had not undergone a surgery in the lumbar area. Also, participants were excluded if they reported a recent history (within a year) of LBP. The participants gave their informed written consent after receiving information regarding the goals and procedures of the study. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (29) and was approved by the Aristotle University Ethics Committee.

Protocol
LM muscle thickness was acquired, bilaterally at the L5 vertebrae level, with the use of two synchronized US devices (SSD-3500, ALOKA, Japan and GE LOGIQ 400 CL PRO, GE Medical Systems, U.K) provided with linear array probes of 10 MHz wave frequency and a length of 6 cm. Two investigators operated each ultrasound unit and did all the scanning for this study, for all participants simultaneously. One of them had 7-year experience in the use of US and the other had finished 1-year practice with the specific protocol prior to commencement of this study.

Prior to measurements each participant was familiarized to the procedures by being instructed in and practicing the exercises to be performed, until they could correctly execute each exercise. For the measurements from the prone position, the participant was positioned on a therapy bed in a relaxed position with both hands lying next to the body. For the superman-RU exercise, the participants were asked to lift the right upper extremity, with the elbow fully extended and the shoulder abducted at 180°. During the superman-RL only the right lower extremity was lifted, by extending the hip, knee and ankle joints. Finally, for the superman-UL exercise the participants were instructed to lift both upper and lower extremities at the same time, with elbows extended and shoulders abducted at 180° and legs extended at the knee and ankle joints. The quadruped position was assumed by placing the hands shoulder-width and the knees on the bed, right below the shoulder and hip joints, respectively. The bird dog-RU was performed by lifting the right arm to the horizontal level, at 180° shoulder abduction. The bird dog-RL exercise performed with right leg raise to 0° hip extension. The last exercise (bird dog-LURL) was executed by lifting, the left upper extremity to 180° shoulder abduction and the right lower extremity to 0° hip extension, at the same time. The duration of the contractions was approximately 10 s, in order US images to be captured. Within this contraction period the participants were asked to take a breath and hold it and then, US images for both sides were frozen, simultaneously. A resting interval of 1 minute was included between each exercise trial. During data collection, all the testing conditions were completed without pain or discomfort. The experimental exercises were performed in a randomized order.

For the acquisition of the US images the two transducers were initially placed longitudinally along the spine with the mid-point over the L4 spinous process. They were, then, moved laterally and turned slightly medially until the L4/5 zygapophyseal joint could be identified (16). At this point the probe is directly over LM muscle and after ensuring a good visualization at the US screen, marks were drawn on the skin with a surgical marker, for consistency during measurements. LM muscle thickness measurements were obtained via the electronic on-screen calipers of the US software. Muscle thickness was expressed as the distance between the facet joint and the plane between the subcutaneous tissue and LM multifidus muscle (Figure 2).

In each testing position, the LM thickness measurements which were acquired during each exercise were normalized to the corresponding thickness at rest. The contraction thickness ratio (CTR), was calculated as the percentage change from rest to exercise using the following equation: $\text{thickness}_{\text{contraction}} - \text{thickness}_{\text{rest}} / \text{thickness}_{\text{rest}}$. To reduce variability by approximately 50% (22), the mean of three trials was used.

Statistical Analysis
Data were checked for normality using the Kolmogorov-Smirnov test. A two-way mixed analysis of variance (ANOVA) design was used to determine the effect of condition (8 levels) and side (left and right) on LM muscle thickness. If significant, a post-hoc analysis Tukey test was applied to determine significant differences between various pairs of means. A separate two-way mixed ANOVA was applied to examine the differences in contraction thickness ratio (CTR) between six exercises and two sides of LM muscle. Post-hoc Tukey test was applied to determine significant differences between various pairs of means. The generalized eta squared values (η^2) were calculated as a measure of effect sizes for each independent variable and their interaction. The level of significance was set at $\alpha = 0.05$.

Ten of the recruited participants returned to the laboratory for a re-test measurement two days after the first session. Re-testing was performed exactly as the first testing session. Each of the two investigators operated the same US unit and tested the same muscle side. They both remained blind to each other's assessment of muscle thickness during the testing process. The generated data from these 10 participants were used for the reliability analysis of the study.

An ICC was calculated to assess intra-examiner reliability ($ICC_{2,1}$) with a 95% confidence interval (CI: 95%) based on the average of 3 measurements per session. An ICC value ≤ 0.50 was considered low, 0.50 to 0.75 moderate, ≥ 0.75 good and ≥ 0.90 excellent (20). Agreement between the measurements was examined using Bland-Altman analysis (Bias ± limits of agreement (LoA) (25). Bias was calculated as the absolute difference in thickness (mm) between test and retest sessions; values closer to 0 indicated greater agreement. The LoA was calculated as 1.96*SD representing a measure of random error between measurement sessions. In addition, the standard error of measurement (SEM) was calculated using the following formula:

$$SEM = SD * \sqrt{1 - ICC}.$$

RESULTS

Mean (± SD) values for both sides of LM muscle thickness at all 8 conditions are presented in Table 1. The ANOVA showed a non-statistically significant Condition by Side effect on muscle thickness ($F_{7, 280} = 0.13$, $p > 0.05$). However, there was a significant main effect of Condition ($F_{7, 280} = 145.45$, $p < 0.05$, $\eta^2 = 0.78$). Post-hoc Tukey tests revealed that muscle thickness was significantly lower at rest (both prone and quadruped) compared with all exercise conditions ($p < 0.05$) except from the bird dog-RU exercise. Moreover, muscle thickness during superman-UL was significantly greater compared with the other exercises ($p < 0.05$). Further, compared to the exercises that implemented lower extremity lift (superman-RL, bird dog-RL and bird dog-LURL) muscle thickness was significantly lower during upper extremity lifting exercises (superman-RU and bird dog-RU) ($p < 0.05$). Finally, no significant differences in thickness between sides ($F_{1, 40} = 0.006$, $p > 0.05$) were found.

Table 1. Mean (± SD) thickness of left and right lumbar multifidus (LM) in each testing condition. Mean percentage (%) differences (± standard error of measurement) between each exercise and resting condition are also reported.

Condition	Left LM (mm)	CTR (%)	Right LM (mm)	CTR (%)
Rest Prone	30.03 ± 3.51		30.26 ± 3.13	
Superman-RU	37.39 ± 4.88	24.80 ± 11.52	37.03 ± 5.30	22.69 ± 15.29
Superman-RL	40.83 ± 4.56	33.43 ± 12.66	40.89 ± 3.39	33.18 ± 10.14
Superman-UL	42.70 ± 5.44	42.84 ± 15.58	43.05 ± 4.64	42.95 ± 14.54
Rest Quadruped	29.86 ± 4.05		29.98 ± 3.18	
Bird dog-RU	31.68 ± 4.25	6.09 ± 13.79	31.24 ± 4.05	3.62 ± 11.89
Bird dog-RL	39.25 ± 3.94	31.48 ± 12.47	39.61 ± 3.72	31.42 ± 10.04
Bird dog-LURL	39.89 ± 4.51	36.54 ± 11.74	40.21 ± 4.32	35.85 ± 11.15

Note. n = 21, CTR = contraction thickness ratio; LURL = Left Upper and Right Lower extremity lift; RL = Right Lower Extremity lift; RU = Right Upper Extremity lift; UL = upper and lower extremities lift.

Group CTR values in each of 6 exercise conditions are presented in Figure 1. The ANOVA showed a non-statistically significant Condition by Side effect on CTR ($F_{5, 200} = 0.16$, $p > 0.05$). However, there was a significant main effect of Condition ($F_{5, 200} = 96.40$, $p < 0.05$, $\eta^2 = 0.70$). Post-hoc Tukey tests revealed that superman and bird dog exercises were significantly different in terms of CTR, only in the superman-UL variation, which yielded the greatest CTR compared to the other exercises ($p < 0.05$). Further, the CTR of the exercises that implemented lower extremity lift (superman-RL, bird dog-RL and bird dog-LURL) was significantly greater compared with the upper extremity lifting exercises (superman-RU and bird dog-RU) ($p < 0.05$). Finally, no significant differences in CTR between sides ($F_{1.40} = 0.08$, $p > 0.05$) were observed.

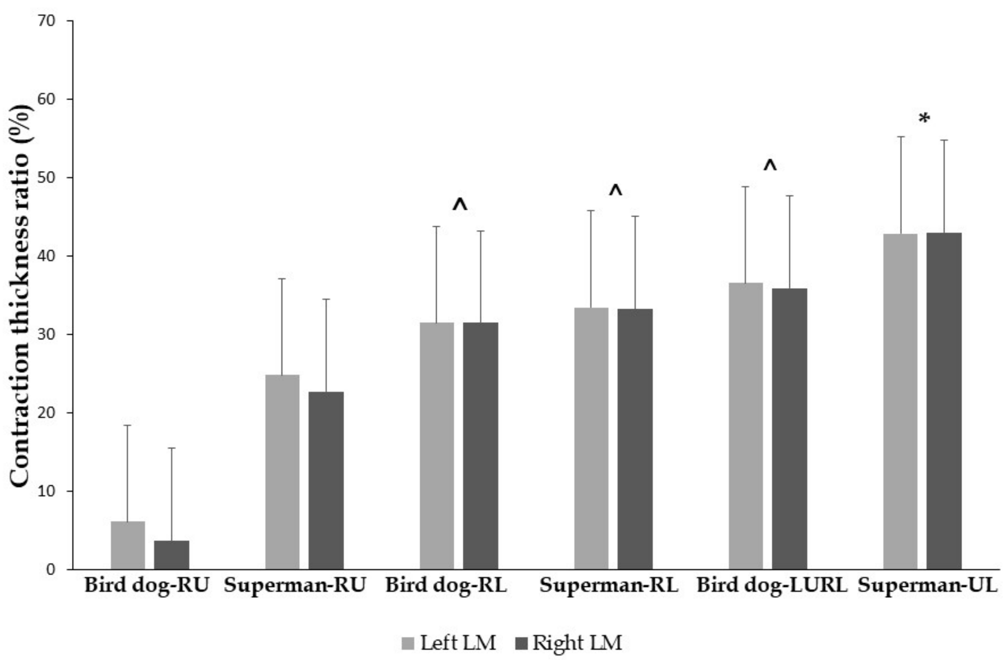

Figure 1. Mean group values of the contraction thickness ratio (CTR) of the LM muscle left and right side in each exercise condition (error bars indicate standard deviation). * significantly different compared with each exercise condition, ^ significantly different compared with Superman-RU and bird dog-RU, $p < 0.05$.

Reliability results for muscle thickness are presented in Table 2. The $ICC_{2,1}$ values ranged from 0.86 to 0.98 for the left side of LM muscle and from 0.87 to 0.98 for the right side of LM muscle. In absolute terms, the SEM values ranged from 0.01 mm to 0.78 mm and from 0.06 mm to 0.57 mm for left and right side of LM muscle, respectively. The systematic error was low, ranging from -0.33 to 0.93 mm for left side and from -0.50 to 1.55 mm for right side. The random error ranged between -1.34 – 2.29 mm for left side and between -1.37 – 3.79 mm for right side of LM muscle.

Table 2. Reliability values for LM muscle thickness in different exercises.

Exercise	Side	Test	R-test	$ICC_{2,1}$	SEM	Bias	Lower LoA	Upper LoA
Rest Prone	Left	30.74 ± 2.55	31.07 ± 2.37	0.89	0.01	-0.33	-1.12	0.46
	Right	31.36 ± 2.71	31.86 ± 2.76	0.90	0.06	-0.50	-1.37	0.37
Superman-RU	Left	36.62 ± 3.17	36.60 ± 3.22	0.98	0.07	0.02	-0.34	0.38
	Right	36.79 ± 3.73	36.92 ± 3.74	0.98	0.08	-0.13	-0.55	0.29
Superman-RL	Left	39.97 ± 4.37	39.70 ± 3.98	0.95	0.27	0.27	-0.61	1.15
	Right	41.48 ± 3.06	41.20 ± 3.00	0.87	0.55	0.38	-0.71	1.47
Superman-UL	Left	41.37 ± 4.98	40.68 ± 4.70	0.97	0.26	0.69	-0.06	1.44
	Right	42.28 ± 3.78	41.94 ± 3.61	0.98	0.08	0.34	-0.07	0.75
Rest Quadruped	Left	29.13 ± 3.15	29.18 ± 3.84	0.86	0.67	-0.05	-1.34	1.24
	Right	30.68 ± 3.53	30.49 ± 3.64	0.97	0.12	0.19	-0.33	0.71
Bird dog-RU	Left	31.55 ± 3.89	30.77 ± 4.24	0.86	0.78	0.78	-0.73	2.29
	Right	31.72 ± 4.12	30.92 ± 4.12	0.90	0.57	0.80	-0.51	2.11
Bird dog-RL	Left	38.75 ± 4.55	37.82 ± 4.68	0.95	0.30	0.93	-0.04	1.90
	Right	39.37 ± 4.33	39.22 ± 4.20	0.98	0.44	1.55	-0.69	3.79
Bird dog-LURL	Left	38.69 ± 4.91	38.88 ± 4.68	0.97	0.23	-0.19	-0.93	0.55
	Right	39.65 ± 4.55	39.54 ± 4.77	0.98	0.14	-0.19	-0.93	0.55

Note. Measures of reliability: ICC = intraclass correlation coefficient; SEM = standard error of measurement; Bias ± LoA = 95% limits of agreement; LURL= Left Upper and Right Lower extremity lift; RL = Right Lower Extremity lift; RU = Right Upper Extremity lift; UL = upper and lower extremities lift.

DISCUSSION

The main findings were that: a) the LM thickness and CTR were significantly greater during superman-UL compared with all the other exercises, b) LM thickness and CTR were greater when the lower extremity was lifted compared with upper extremity lifting tasks and, c) no bilateral differences in thickness were observed during all exercise conditions.

Of all exercises, the superman-UL showed the highest LM thickness and CTR (Table 1). Hwang and Park (13) reported that during the superman-UL, LM thickness increased approximately by 34% compared to rest, which is line with the present study. Previous EMG studies also demonstrated that the superman exercise shows activity levels over 60% of maximum voluntary contraction (MVC) which is greater than that observed in the bird dog exercises (6, 17, 32). EMG studies have shown that superman-UL displays EMG activation in the range of 62-82% MVC (6, 32) which is greater than that observed during bird dog-LURL (6, 32, 38). The greater CTR observed during the superman-UL could be attributed to a greater lumbar extension while the bird dog exercise mostly requires spinal alignment. Paraspinal muscles like the LM, apart from controlling spinal motion in the transverse and sagittal planes contribute to lumbar extension movements (14, 23, 24). It is possible that superman-UL exercise yielded a greater CTR compared to the bird dog exercise since it challenges both the ability of LM muscle to maintain the orientation of the lumbar spine, while acting as an extensor. In contrast, during bird dog exercise, LM muscle is activated in order to maintain the alignment of the spine , by resisting torsional forces created from the opposing upper and lower extremity lift (27). Based on this finding, it could be suggested that the superman-UL exercise can be incorporated in the final stages of performance difficulty, in stabilization training programs with unloaded isometric exercises.

The results of this study indicated that the exercises with lower extremity lifting showed greater LM CTR than those incorporating upper extremity lifting (Figure 2 and Figure 3). More specifically, CTR during superman-RU and bird dog-RU ranged from 3 to 24%, while during the superman-RL and bird dog-RL exercises from 31 to 34% (Table 1). This is in agreement with previous studies which examined upper and lower extremity lifts either from the quadruped or the prone position (13, 17). The differences in measured thickness between exercises may be the result of a difference in stability between them. By lifting the upper or lower extremities of the ground, the base of support decreases, increasing the instability and thereby, it triggers the trunk stabilization muscles to contract in order to maintain an aligned spine (17). Further, there is evidence that during arm lifting tasks, global/local (erector spinae/LM) activation ratio is higher compared to leg lifting tasks (17, 27, 38) which may provide an additional explanation of our findings. Therefore, taking into account that the exercises we applied had a different impact on LM thickness, upper extremity lifting exercises (superman-RU and bird dog-RU) could be performed first at early stages of rehabilitation or in the case of well-trained individuals disregarded, followed by lower extremity raises (superman-RL and bird dog-RL), opposing upper and lower extremity lifting exercises (bird dog-LURL) and last, the superman-UL, where all the extremities are lifted, as the most effective of these exercises, to recruit this muscle.

Even though our exercises required unilateral upper or lower extremity movements, there were no significant differences in thickness between left and right LM muscle thickness (Table 1). In fact, both sides of the LM displayed excellent symmetry in size, during rest and contraction (Figure 2 and Figure 3). This was the first study that examined bilateral differences in LM muscle thickness, during graded exercises from prone and quadruped position, using two synchronized US devices. Our results are in contrast to previous studies which reported significant asymmetries in LM size and recruitment between sides (6, 27, 30, 38). For example, Niemeläinen et al., (30) observed that many healthy adults had asymmetry in LM cross-sectional area between sides greater than 10%. In addition, it has been reported that during bird dog-LURL, LM activation is greater on the side of the lifted leg compared to the activity of the contralateral side. (27, 38). In advance, Masaki et al., (27) found that opposing shoulder and hip abduction movements from the quadruped position resulted in higher LM activation on the side of the lower extremity lift as opposed to the contralateral side. However, these studies (7, 27, 38) used EMG electrodes and, hence, direct comparison with our findings is difficult. It is also possible that the ability of individuals to trigger and affect LM unilaterally, depends on the presence of asymmetry between sides (3). Therefore, based on our observations, unilateral activation/contraction patterns of LM muscle might not be apparent and hence, segmental training is not feasible, at least in healthy individuals with no asymmetries in LM muscle thickness.

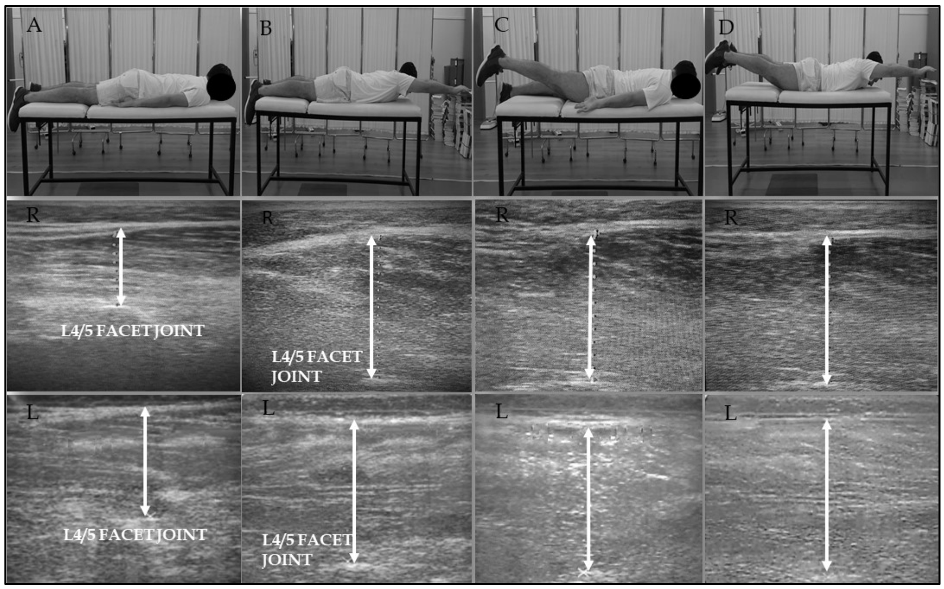

Figure 2. Illustration of the ultrasound measurement technique of left (L) and right (R) LM muscle at (A) prone rest, (B) superman- right upper extremity lift (RU), (C) superman-right lower extremity lift (RL) and (D) superman-upper and lower extremities. Thickness measurements were made between the superficial and deep borders of LM muscle (drawn with line).

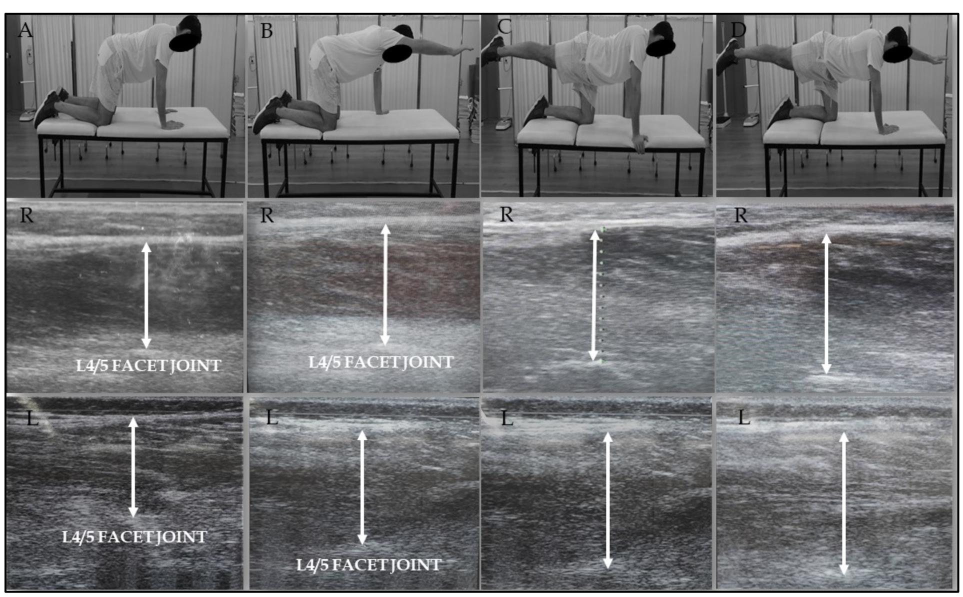

Figure 3. Illustration of the ultrasound measurement technique of left (L) and right (R) LM muscle at (A) quadruped rest, (B) bird dog- right upper extremity lift (RU), (C) bird dog-right lower extremity lift (RL) and (D) bird dog-left upper right lower. Thickness measurements were made between the superficial and deep borders of LM muscle (drawn with line).

The present study has several limitations. First, the research was conducted with recreationally active males with no musculoskeletal injuries. This restricts the results from representing all ages, both genders and patients with LBP problems, who may have altered lumbar muscle activity and contraction ability. Second, the amount of loading in intervertebral joints during these graded exercises is not clear, even though they have been proposed as safe for athletes and patients (9, 12). Moreover, the examination of other surrounding muscles, when performing these exercises, such as the erector spinae and gluteal muscles would give further information, for the contribution of each muscle to the movement. Our design did not include performance of the superman exercise with contralateral upper and lower extremity raises. This would allow a better comparison of superman and bird-dog exercises; instead, we chose to examine the superman-UL exercise, as it was examined in previous studies (6, 13, 17). Finally, US technology, although is established as reliable and valid in measuring changes in muscle morphology, remains an indirect method for the assessment of muscle activity compared with EMG. This could be a possible explanation for not detecting bilateral differences in LM muscle.

The results of this study indicated that LM CTR was greater during superman compared with bird dog exercises. Further, LM CTR increased progressively when superman or bird dog exercises were performed in the following order: only upper extremity raised, only lower extremities raised and finally, combined upper and lower extremities raised. No side to side differences in LM muscle thickness were observed in any testing condition. These findings can be used to set exercise program progression when designing exercise interventions for the LM.

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