CHAPTER 3

METHOD

3.1 Comparison of lateral abdominal muscles size between weightlifters and matched control subjects

3.1.1 Introduction

Competitive weightlifting is a sport that emphasizes explosive muscular power and exposes the spine to extreme forces during competition and training. Olympic style weightlifting demands high levels of dynamic force using both the upper and lower extremities, with the trunk musculature serving as both stabilizers and primary movers [30]. Exposure to high loads and repetitive motion may over time lead to increased stress on the joints and other soft tissues. The average injury rate in weightlifters has been documented at 3.3 injuries/ 1000 [30] . Anatomical areas at the greatest risk for injury with Olympic style weightlifting are the low back (23.1%), the knee (19.1%) and the shoulder (17.7%) [28, 30]. Due to the heavy loading and techniques required in Olympic style weightlifting the back is particularly at risk.

The lumbar spine is controlled by both local and global muscle systems. [3, 90]. The global muscles act to transfer loads between the thoracic spine and pelvis and balance external loads. The local muscles act directly on the lumbar vertebra and are considered to be responsible for segmental stability.

The LAM includes the TrA, IO and EO. These muscles share a role in controlling the lumbar spine during activities such as weightlifting. The EO and IO are important for creating rotary torque and balancing external loads while the TrA with its mostly transversely oriented fibers assists in controlling the positions of the lumbar segments through its ability to increase tension of the thoracolumbar fascia [3, 7, 37, 40, 41]. Unlike muscles in the extremities it is difficult to make a direct force measurement of individual abdominal muscles. However, as muscle force has been shown to be associated with a cross-sectional area [91, 92], muscle thickness may provide an indirect measure of muscle function.

Routine training in Olympic style weightlifting consisted of Olympic lifts (the snatch and clean & jerk), power lifts (bench presses, squats and dead lifts) and traditional weight training such as toe rises, back squat, front squat and high pull. Currently, it is not clear how the lateral abdominal muscle adapt to the training program used by weightlifters; therefore, the aim of this study was to compare the thickness of the lateral abdominal wall muscle between weightlifters and matched control subjects.

3.1.2 Methods

3.1.2.1 Subjects

Sixteen female Thai national weightlifters aged 15-27 years who were currently training, and sixteen matched (age, weight and height) controls subjects (recruited from a local post-secondary educational institution) participated in this study. Exclusion criteria included; history of low back pain in past three months, significant spinal deformity, history of lumbar surgery, history of neuromuscular or joint diseases or neurological conditions affecting the trunk or pregnancy. Control subjects were required to have not engaged in a regular exercise program greater than 2 times/week for the 8 weeks preceding data collection, while the weightlifting subjects were required to have participated in at least one full year of regular weightlifting training to participate in the study. Written informed consent was obtained from all subjects. The ethical clearance was granted by the Human Research Ethical Committee of the Faculty of Associated Medical Sciences, Chiang Mai University.

3.1.2.2 Procedure

Ultrasound Measurements Ultrasound images of the right lateral abdominal wall were obtained using an ultrasound scanner (Toshiba, Famio 8, SSA-530A) in B-mode with a 12-MHz linear array transducer. Subjects were positioned on a plinth in crook lying with a pillow under their head and the knees. Ultrasonic gel was interposed between the transducer and the skin. The transducer was placed in a transverse plane just superior to the right iliac crest along the axillary line [(7)]. To standardize the location of the transducer was obtained following techniques as described in Appendix 1. Images of LAM and measurements were obtained using NIH (Bedthesda, MD) Image J software (V 1.38t) (http://rsb.info.nih.gov/nih-image/) (Figure A1-2). Each measurement was repeated three times and the mean used to calculate an absolute and relative (percent total muscle thickness) thickness value.

3.1.2.3 Statistical analysis

The Kolmogorov-Smirnov test was used to test demographic and measured data for normality. Data were not found to be normally distributed and therefore non parametric statistical tests were used for further analysis. Demographic data and muscle thickness between weightlifters and controls were compared using Mann-Whitney U tests. Power analysis was determined.

3.1.3 Results

Demographic data analysis revealed no significant differences (*p*> 0.05) in age, weight, height and BMI of the weightlifters versus the controls. Therefore the subjects were assumed to be well matched (Table 3-1).

Weightlifters had significantly thicker absolute LAM than match controls except EO (ES > 0.8, *p*<0.01) as shown in Table 3-2. Further, the relative thickness of the IO was significantly thicker in weightlifters than match controls (ES= 0.57, *p*<0.05) (Table 3-3). The pattern of descending order of relative thickness was IO > EO > TrA (Figure 3-1).

Table 3-1 Characteristics of subject groups

Characteristics	**Weightlifters (n = 16)**	**Controls (n = 16)**	***P*- value**
Age (yr)	19.88 ± 2.60	21.38 ± 2.58	0.06
Height (m)	153.74 ± 5.75	158.28 ± 5.80	0.06
Body mass (kg)	56.41 ± 5.27	57.44 ± 10.77	0.85
Body mass index (kg/m^2)	23.86 ± 1.80	22.79 ± 3.16	0.14
Experience of training (yr)	5.91 ± 3.49	-	N/A

Table 3-2 Comparison of absolute lateral abdominal muscle thickness between weightlifters and matched controls

Thickness (mm)	Weightlifters (n=16)		Controls (n=16)		Effect size	*P* value
	Mean ± SD	**95%CI**	**Mean ± SD**	**95%CI**		
TrA	3.2 ± 0.8	2.8 - 3.6	2.4 ± 0.8	2.0 - 2.7	0.88[a]	0.01*
IO	9.9 ± 2.7	8.5 - 11.4	6.9 ± 1.4	6.1 - 7.6	0.98[a]	0.001*
EO	7.0 ± 1.7	6.1 - 7.9	5.9 ± 1.4	5.1 - 6.7	0.64	0.08
IEO	17.5 ± 2.9	15.9 - 19.1	13.4 ± 2.1	12.3 - 14.6	0.99[a]	0.001*
Total	21.5 ± 3.4	19.7 - 23.3	16.7 ± 2.4	15.4 - 17.9	0.99[a]	0.001*

Significant differences between weightlifters and matched controls are indicated by $*P<0.01$.

Table 3-3 Comparison of relative lateral abdominal muscle thickness between weightlifters and matched controls

%Thickness	Weightlifters (n=16)		Controls (n=16)		Effect size	*P* value
	Mean ± SD	**95%CI**	**Mean ± SD**	**95%CI**		
TrA/Total (%)	14.8 ± 2.5	13.5 - 16.1	14.2 ± 3.3	12.5 - 15.9	0.14	0.41
IO/Total (%)	45.6 ± 6.8	41.9 - 49.2	41.3 ± 6.5	37.8 - 44.8	0.57	0.04*
EO/Total (%)	33.1 ± 6.9	29.4 - 36.8	35.3 ± 6.2	31.9 - 38.6	0.24	0.31
IEO/Total (%)	81.4 ± 3.4	79.6 - 83.3	80.6 ± 3.4	78.8 - 82.4	0.16	0.55

Significant differences between weightlifters and matched controls are indicated by $*P<0.05$.

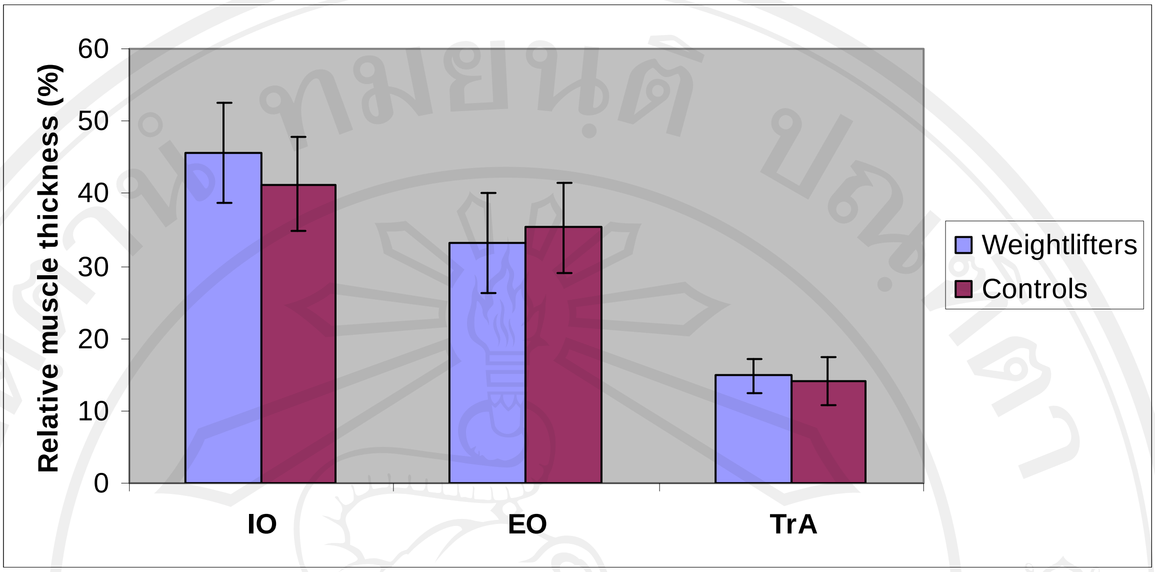

Figure 3-1 Relative muscle thickness of LAM (mean $\pm$ SD). The muscles are shown in order of descending relative thickness; the same order is seen in both weightlifters and matched controls.

3.1.4 Discussion

To our knowledge, this is the first study to evaluate the LAM thickness of Olympic style weight training program using ultrasound imaging. In both female weightlifters and matched control subjects, a characteristic descending order of muscle thickness was demonstrated, IO being thickest, then EO and TrA. This characteristic showed the same order of LAM thickness as previous study [93]. This may be a simple and useful way of assessing normality, particular for rapid clinical assessment of muscle imbalance. Alternation in the order of muscle thickness could indicate a selective muscle atrophy or hypertrophy of the LAM [93].

Weightlifters had significantly thicker absolute LAM thickness than matched controls. The results was supported by previous studies [93, 94] that muscle thickness at rest of elite male athletes was thicker than the moderately active subjects. The possible explanation for this is muscle hypertrophy in the athletes is due to strenuous training and competition. Physiological muscle overload, which demands relatively high proportion of maximum voluntary strength such as weightlifting, is known to result in hypertrophy of fast-twitch fibers [95]. Strenuous weight training programs affect trunk stability, thus the LAM has to adapt via hypertrophy.

Relative IO thickness of weightlifters was thicker than matched controls. The IO is part of the global system and is responsible for transferring load between the pelvis and thorax as well as balancing external loads. Both functions are required during weightlifting; this may result in preferential adaptation of this muscle in weightlifters.

Hypertrophy of IO muscle may be a result of using alteration patterns in repeated rapid movements during lifting. This process may activate superficial muscles including IO for global stabilization. In a retrospective study of individuals with unilateral lower limb amputations, the IO and EO muscles were found to be larger in size on the ipsilateral side of the amputated limb [96]. This finding suggests that the superficial abdominal muscles hypertrophy on the side of amputation due to a result of altering or compensation in movement patterns with ambulation.

Relative TrA thickness was not found to be hypertrophy in weightlifters. This may be due to the fact that the role of TrA is to activate in anticipation of loads to the spine contributing to segmental stabilization and intra-abdominal pressure. Previous studies also suggest that TrA is involved in the role of motor control rather than strength [39, 96]. Although, the present study found that routine Olympic weight training program such as snatch, clean and jerk, bench press, squat, curl up and back extension appears to increase the thickness of the IO while not affecting the thickness of the TrA. Further study is required to investigate this relationship in weightlifters with low back pain.

It should be noted that only a small number of female national weightlifters were available for recruitment into this study, which is a typical consequence in studies focused on elite athletes. Furthermore, only LAM was examined in this study. Other trunk muscles which may contribute to segmental control of the lumbar vertebrae in the complex skill of weightlifting such as lumbar multifidus and other superficial trunk muscles were not included in this present study. Further research is warranted to consider the contribution of these muscles in weightlifters.

In conclusion, the female weightlifters in this study demonstrated significantly larger absolute lateral abdominal muscles thickness. Further this population demonstrates a larger relative IO muscle thickness than matched control. The findings suggest that Olympic weightlifting training appear to preferentially influence the thickness of internal oblique muscle.

3.2 Thickness of lateral abdominal muscles in elite female Thai weightlifters

3.2.1 Introduction

LPS can be explained based on the neuromuscular control required around the lumbar spine to maintain functional stability and protect the spine from injury [(1)]. Stabilization of the lumbar spine is partly due to the action of LAM, which comprise of TrA, IO and EO [(7)]. Stabilization of the spine is very important in weightlifting events. Muscles acting on LPS included local and global stabilizing systems [90]. The global stabilizing muscles (eg. rectus abdominis, EO and IO) act as load transfers between spine and pelvis. Global muscles balance external loads that help to minimize the resulting forces on the spine. The local stabilizing muscle such as TrA is a segmental stabilizer which controls the position of the lumbar segments. Therefore, LAM has an important role in stabilizing the lumbar spine and this has implication for the management and prevention of LBP. Previous studies had highlighted the important role played by the TrA muscle in stability and protection of the lumbar spine [36, 39, 45, 46].

Clinical assessment of TrA muscle performance has mainly involved observation of the abdominal drawing-in maneuver (ADIM) [3] and used as a foundation for lumbar stabilization exercise. RUSI has been used previously to measure abdominal size in healthy sedentary subjects [93]. Rankin et al [93] demonstrated that males have significantly larger abdominal muscles than females and size is poorly correlated with age. An investigation on characteristics descending order of muscle size demonstrated that rectus abdominis was larger than IO, EO and TrA, respectively. This information could be used to assess imbalance within abdominal muscle groups. Normal abdominal muscle thickness has been reported in sedentary subjects and has proved useful for assessing abnormality in patients with LBP. However, the LAM thickness in athletes who required more muscle functions to control LPS, such as Olympic style weightlifter, has never been reported. The aim of the present study was to investigate the LAM muscle thickness in elite female weightlifters.

3.2.2 Methods

3.2.2.1 Subjects

Sixteen female Thai national weightlifters participated in this study. Subjects with history of low back pain in the past three months, significant spinal deformity, history of lumbar surgery, history of neuromuscular or joint disease or neurological conditions affecting the trunk or pregnancy were excluded. The study was approved by Human Experimental Committee of Faculty of Associated Medical Sciences, Chiang Mai University. Informed consent was obtained from all subjects.

3.2.2.2 Procedure

Subject Familiarization Subjects were positioned in a supine crook lying position, with 45° of hip flexion. A pressure biofeedback unit (PBU) (Chattanooga, Hixson, TN) was placed under lumbar spine and inflated to 40 mmHg. Subjects were provided with standard instructions to contract TrA muscle independently of the other abdominal muscles using ADIM: "Take a relaxed breath in and out, hold the breath out, and then draw in your lower abdominal up and in towards your spine without moving your spine". Subjects were asked to keep the pressure level during ADIM [3, 7, 15].

Ultrasound image assessment Toshiba ultrasound scanner (Toshiba, Famio 8, SSA-530A) was used in B-mode with a 12-MHz linear transducer to investigate LAM thickness. Ultrasound image of the TrA was taken bilaterally from each subject in the same position as the familiarization procedure. Subjects were given one practice of ADIM before image acquisition. Images of LAM thickness were obtained following techniques as describes in Appendix 1. Images were taken at the end of exhalation when the subjects were relaxed and during contraction while hold the ADIM. During testing, subjects performed three ADIM with 2-minutes rest. First ADIM was practiced and ultrasound image was performed at the second ADIM on the left and right sides in a randomized order. The subjects were not able to see the ultrasound monitor and did not receive feedback of performing ADIM. Images were stored for offline analysis and measured using Image J program (V 1.38t). Absolute thickness of LAM muscle was calculated by average between left and right side. Relative thickness of each LAM was calculated by absolute thickness divided by total abdominal muscle thickness. The contraction ratio was calculated by the thickness during contraction divided by the resting thickness.

3.2.2.3 Statistical analysis

The LAM size was represented by the muscle thickness and expressed as mean, SD and the ranges of values for 95% of the sample population (mean $\pm$ 2SD) for absolute and relative muscle thickness. Differences in muscle size of the left and right measurements were analyzed using paired *t*-tests.

3.2.3 Results

Characteristics of elite Thai female weightlifters are shown in Table 3-4. Absolute thickness and relative thickness are shown in Table 3-5 and 3-6. Significant differences between left and right sides were found in absolute thickness of IO and relative thickness of TrA and IO ($p<0.05$). Contraction ratio was demonstrated in Table 3-7. There were no significant difference between left and right sides ($p>0.05$).

Table 3-4 Characteristics of elite Thai national female weightlifters (n=16)

Characteristics	**Mean ± SD**	**Range**
Age (yr)	21.31 ± 3.30	18-28
Height (cm)	154.87 ± 9.03	145-179
Body mass (kg)	63.50 ± 18.45	50-117
Body mass index (kg/m^2)	26.01 ± 4.07	21.75-36.36
Experience of training (yr)	7.63 ± 3.14	3-14

Table 3-5 Absolute lateral abdominal muscle thickness in elite Thai national female weightlifters (n=16)

Muscle thickness (mm)	**Right**		**Left**	
	Mean ±SD	**(95%range)**	**Mean ± SD**	**(95%range)**
TrA	3.24 ± 0.83	(1.58 - 4.90)	3.22 ± 0.75	(1.72 - 4.72)
IO	10.55 ± 2.81	(4.93 - 16.17)	8.48 ± 1.69	(5.10 - 11.86)*
EO	7.29 ± 1.58	(4.13 - 10.45)	6.72 ± 1.17	(4.38 - 9.06)
IEO	18.41 ± 2.55	(13.31 - 23.51)	15.99 ± 2.11	(11.77 - 20.21)*
Total LAM	22.35 ± 3.21	(15.93 - 28.77)	20.02 ± 2.72	(14.58 - 25.46)*

Abbreviations: Transversus abdominis muscle (TrA), Internal oblique muscle (IO), External oblique muscle (EO), Internal and external oblique muscles (IEO) and Total lateral abdominal muscle (Total LAM)

***** statistical significant difference between right and left side at $p < 0.05$

Table 3-6 Relative lateral abdominal muscle thickness in elite Thai national female weightlifters (n=16)

Relative muscle thickness (%)	**Right**		**Left**	
	Mean ± SD	**(95%range)**	**Mean ±SD**	**(95%range)**
TrA/Total (%)	14.39 ± 2.23	(9.93 - 18.85)	16.02 ± 2.42	(11.18 - 20.86)*
IO/Total (%)	46.71 ± 7.01	(32.69 - 60.73)	42.24 ± 5.33	(31.58 - 52.90)*
EO/Total (%)	33.26 ± 7.69	(17.88 - 48.64)	33.82 ± 5.82	(22.18 - 45.46)
IEO/Total (%)	82.49 ± 2.87	(76.75 - 88.23)	79.94 ± 2.67	(74.60 - 85.28)*

Abbreviations: Transversus abdominis muscle (TrA), Internal oblique muscle (IO), External oblique muscle (EO), Internal and external oblique muscles (IEO) and Total lateral abdominal muscle (Total LAM)

***** statistical significant difference between right and left side at $p < 0.05$

Table 3-7 Contraction ratio of lateral abdominal muscle in elite Thai national female weightlifters (n=16)

contraction ratio	Right		Left	
	Mean ± SD	**(95%range)**	**Mean ± SD**	**(95%range)**
TrA				
Resting thickness (mm)	3.24 ± 0.83	(1.58 - 4.90)	3.22 ± 0.75	(1.72 - 4.72)
ADIM thickness (mm)	6.19 ± 1.69	(2.81 - 9.57)	5.75 ± 1.51	(2.73 - 8.77)
Contraction ratio	**1.96 ± 0.55**	**(0.86 - 3.06)**	**1.81 ± 0.39**	**(1.03 - 2.59)**
IO				
Resting thickness (mm)	10.55 ± 2.81	(4.93 - 16.17)	8.48 ± 1.69	(5.10 - 11.86)
ADIM thickness (mm)	12.65 ± 2.76	(7.13 - 18.17)	10.27 ± 2.00	(6.27 - 14.27)
Contraction ratio	**1.22 ± 0.13**	**(0.96 - 1.48)**	**1.23 ± 0.19**	**(0.85 - 1.61)**
IEO				
Resting thickness (mm)	18.41 ± 2.55	(13.31 - 23.51)	15.99 ± 2.11	(11.77 - 20.21)
ADIM thickness (mm)	19.04 ± 2.96	(13.12 - 24.96)	16.18 ± 2.43	(11.32 - 21.04)
Contraction ratio	**1.03 ± 0.05**	**(0.93 - 1.13)**	**1.01 ± 0.06**	**(0.89 - 1.13)**
Total LAM				
Resting thickness (mm)	22.35 ± 3.21	(15.93 - 28.77)	20.02 ± 2.72	(14.58 - 25.46)
ADIM thickness (mm)	26.04 ± 4.29	(17.46 - 34.62)	22.95 ± 3.61	(15.33 - 30.57)
Contraction ratio	**1.17 ± 0.09**	**(0.99 - 1.35)**	**1.15 ± 0.11**	**(0.93 - 1.37)**

Abbreviations: Transversus abdominis muscle (TrA), Internal oblique muscle (IO), External oblique muscle (EO), Internal and external oblique muscles (IEO) and Total lateral abdominal muscle (Total LAM), Abdominal drawing-in maneuver (ADIM)

3.2.4 Discussion

The current study is the first study that provided the LAM thickness and contraction performance among elite female weightlifters. All elite female weightlifters participated in the practice training program in national camp. The order of relative LAM size was determined from the mean values. A characteristic of descending order of muscular size was demonstrated, IO being thickest, then EO and TrA. This characteristic is similar to previous study investigated in normal subjects [93]. The order of muscle size may be used as a rapid clinical assessment of muscle imbalance. Alternation of the order of muscle size could indicate selective atrophy [93], which can be quantified using the data presented (Table 3-6).

Absolute thickness of TrA and EO in elite female weightlifters showed no significant differences between sides, whereas, the right IO was significantly larger than the left one ($p<0.05$). Differences between sides were also found in relative thickness of TrA and IO ($p<0.05$). The results were similar to those reported in normal subjects by Rankin [93] (absolute thickness right IO 8.5 mm, left IO 8.1 mm; relative thickness right TrA 12.1 %, left TrA 12.6%, right IO 28.4%, left IO 27.2%). The affecting asymmetry may depend on physical activity levels, frequently dominant side used and anthropometric asymmetry, e.g. minor scoliotic deviation of the spine [97]. Asymmetry between sides may also be due to asymmetrical pattern of lifting in weightlifters; this suggests further investigation of individual lifting biomechanics.

The contraction performance of the LAM in elite female weightlifters was represented by contraction ratio as the proportion of muscle thickness between resting and ADIM stage. ADIM was used to determine the performance of local stabilizer muscles, especially the TrA which to contracted independent of global stabilizer muscles e.g. EO [3, 7]. The current study represents the TrA contraction ratio range from 1.8-1.9 with no difference between sides, similar to those reported in normal subjects by Vasseljen and Fladmark [98] and Mannion et al[99]. Previous studies reported the contraction ratio of TrA of less than 2 in LBP [3, 7]. The greater contraction ratio represents more TrA performance and may result in sufficient LPS and prevention of LBP. The specific stabilization exercise is not included in the routine training program in national weightlifters camp. This suggests further study to investigate TrA performance in weightlifters with LBP and to determine the effect of stabilization exercise on TrA performance.

In conclusion, this study provides new information on the thickness and function of LAM in elite female Thai weightlifters. The assessment of LAM thickness and function may benefit weightlifters for detection of muscle adaptation.

3.3 Transversus abdominis muscles thickness and contraction ratio among elite weightlifters with and without low back pain

3.3.1 Introduction

Weightlifting is a sport that exposes the athletes to extreme force during the training and competitive events. This may cause instability to the spine and lead to LBP [28, 29]. An injury report conducted among weightlifters showed that the incidence of LBP was 23.1% among elite male weightlifters in United State [30] and 28.9% among Thai weightlifters [31]. Lumbopelvic instability is one of the problems found in patients with recurrent and chronic LBP [21, 33]. It is associated with impairments of the deep muscles of the spine, including atrophy [25, 35], delayed activation [19, 36] and a lack of volitional control [13, 20].

Previous studies [3, 5-7, 100] had highlighted the important role played by TrA muscle in stability and protection of the lumbar spine. It had been proposed that the trA muscle may contribute to stabilize the lumbopelvic region as it can cause an increase in IAP and TLF tension[100]. The motor control model of spinal stabilization training is commonly used for LBP treatment [3, 5-7]. The motor control model of spinal stabilization focuses on the function of deep spinal muscles as these structures are thought to have the ability to control motion between vertebral segments. The motor control approach emphasizes that subjects learn to preferentially activate the deep trunk muscles [3], primarily the TrA and LM. Many studies have highlighted the role of TrA and LM in control of the spinal segment's neutral zone, provision of segmental stiffness and capacity to stabilize the spine [8-11].

Clinical assessment of TrA muscle performance has mainly involved observation of TrA contraction during ADIM [3]. Firewire EMG has traditionally been used to assess the TrA magnitude and activity but the invasiveness of these procedures limits their routine clinical use [7, 12]. The action of the TrA muscle has been viewed during RUSI and MRI [24, 94] .There are evidence supporting the use of RUSI as a noninvasive tool to assess deep muscle function [13-16]. The application of RUSI for the purposes of biofeedback and muscle performance measurement by rehabilitation professionals are commonly used to guide clinical intervention [17, 18]. The most common parameter measurable with RUSI that relates to muscle activation is a change in muscle thickness. Several researchers have utilized thickness change as an indicator of muscle activation for the TrA [7, 19-21]. The validity of utilizing muscle thickness change as a measurement of lower level muscle activation has been demonstrated in the TrA [14, 26]. TrA thickness correlated well with less than 30% MVC of TrA.

Recently, researchers have focused on the TrA in its role in providing stability to the lumbopelvic region and its dysfunction in individuals with LBP [33, 94, 101, 102]. In a recent study conducted on elite cricketers[94], the ability to contract the TrA muscle during ADIM was reduced in cricketers with LBP.

As patients with LBP have been shown to demonstrate deficits in motor control of the TrA muscle [33, 94, 101, 102], it is possible that such deficits may occur in weightlifters with LBP. Information of this kind could help in rehabilitation and training program for weightlifters. Therefore, the aim of this study was to investigate the TrA muscle thickness and the ability to contract the TrA muscle among elite female weightlifters with and without LBP.

3.3.2 Methods

3.3.2.1 Subjects

The subjects in this study were sixteen elite female weightlifters who were selected to attend a National training camp. Subjects performed regular weightlifting training program consisted of one hour of cardiovascular and strength training and three hours of skill training per day, 6 days per week. The sample mean ± SD of age, weight and height were 21.3 ± 3.3 years, 63.5 ± 18.4 kg and 154.9 ± 9.0 cm, respectively. The exclusion criteria were spinal abnormality, spinal or abdominal surgery and pregnancy. Subjects who reported current pain localized between T12 and gluteal fold, was allocated to the "LBP group". The study was approved by the Human Experimental Ethics Committee of the

Faculty of Associated Medical Sciences, Chiang Mai University, Thailand. Informed consent was obtained from all subjects.

3.3.2.2 Procedure

All subjects completed self administered questionnaire on pain intensity (visual analogue scale (VAS) rated 0-10) and side of LBP (left / right, as nominated by subject and drawn on a body chart).

The grouping of subjects was based on body chart reports of LBP. Weightlifters who reported no back pain on body chart and during manual examination were coded as 'asymptomatic'. Among the weightlifters, 9 were coded as asymptomatic cases, 7 coded as LBP cases.

Subject Familiarization Subjects were positioned in a supine crook lying position, with 45° of hip flexion. PBU was placed under lumbar spine and inflated to 40 mmHg. Subjects were provided with standard instructions to contract TrA muscle independently of the other abdominal muscles by performing ADIM as described in section 3.2.2.1.

Ultrasound image assessment Toshiba ultrasound scanner (Toshiba, Famio 8, SSA-530A) was used in B-mode with a 12-MHz linear transducer to investigate TrA muscle thickness. Ultrasound image of the TrA was taken bilaterally from each subject in the same position as the familiarization procedure. Subjects were given one practice of ADIM before image acquisition. Images of TrA thickness were obtained following techniques as describes in Appendix 1. Images were taken at the end of exhalation when the subjects were relaxed and during contraction while hold the ADIM following techniques as described in section 3.2.2.1.

Absolute thickness of TrA muscle was calculated by average between left and right side. Relative thickness of TrA was calculated by absolute thickness of TrA muscle divided by total abdominal muscle thickness. The contraction ratio (CR) of TrA was calculated by the thickness during contraction divided by the resting thickness.

3.3.2.3 Statistical analysis

Independent *t*-tested was used to compared TrA muscle thickness and CR between asymptomatic and LBP groups at *p* value 0.05.

3.3.3 Results

The demographic characteristics of the weightlifters are shown in Table 3-8. There were no significant differences for age, height, weight and BMI between the asymptomatic and LBP groups (p>0.05). LBP weightlifters reported a mean pain VAS score of 5.4 $\pm$ 1.6.

Mean and SD for TrA muscle thickness are shown in Table 3-9 for asymptomatic weightlifters and those with LBP. The TrA muscle size represented TrA thickness (mm). There were no significant differences in TrA muscle thickness between the asymptomatic and LBP group (p>0.05). However, the result showed that the elite female weightlifters in LBP group demonstrated significantly lesser CR of TrA when compared to the asymptomatic group (p<0.001) (Table 3-9).

Table 3-8. Characteristics of elite weightlifters (mean ± SD) (n=16)

Variables	Asymptomatic (n=9)	LBP (n=7)	Total (n=16)
Age (yr)	21.56 ± 3.5	21.00 ± 3.3	21.31 ± 3.7
Weight (kg)	62.04 ± 15.5	65.37 ± 22.9	63.5 ± 18.4
Height (cm)	154.94 ± 7.9	154.77 ± 11.0	154.81 ± 9.0
BMI (kg/m^2)	25.54 ± 3.9	26.62 ± 4.5	26.01 ± 4.0
Experience of training (yr)	8.56 ± 3.6	6.43 ± 2.2	7.62 ± 3.1
Maximum snatch lifting (kg)	97.39 ± 14.4	95.07 ± 7.4	96.37 ± 11.6
Maximum clean and jerk lifting(kg)	125.06 ± 15.6	120.29 ± 8.8	122.97 ± 12.9

Table 3-9. Mean and SD of TrA muscle thickness (mm), relative muscle thickness (%) and contraction ratio (CR) of asymptomatic and LBP group

TrA	Asymptomatic (n=9)	LBP (n=7)	*P* value
Absolute thickness (mm)			
Resting	3.11 ± 0.6	3.38 ± 0.8	0.46
Contraction	6.55 ± 1.3	5.23 ± 1.3	0.07
Relative thickness (%)			
Resting TrA/Total	14.63 ± 1.9	15.88 ± 2.0	0.23
Contraction TrA /Total	22.52 ± 3.9	25.49 ± 2.8	0.10
Contraction Ratio	2.13 ± 0.24	1.57 ± 0.33	0.001*

*Difference between asymptomatic and LBP group.

3.3.4 Discussion

TrA is one muscle that plays an important role in segmental stabilization of the lumbar spine. Patients with LBP demonstrated dysfunction of this stabilizing muscle [13, 19, 20, 36]. However, the present study found no difference in TrA muscle thickness between asymptomatic and LBP group of elite female weightlifters. This might be due to the influence of training effect, as the athletes who reported LBP were still training and competing at high levels.

The result showed that the elite female weightlifters with LBP exhibited no deficits in TrA muscle size. The findings were in agreement with the studies of

Critchley & Couts [13] and Norasteh et al [79] that found no differences in TrA muscle thickness at rest between LBP and sedentary people without LBP. In addition, Hides et al [103] reported same range of TrA muscle thickness among elite cricketers with and without LBP. However, previous studies demonstrated that subjects with LBP had a significant smaller increase in TrA muscle thickness during lower abdominal hollowing than both asymptomatic sedentary and athletes [13, 103]. It indicated that LBP patients may have deficit in TrA muscle function than the atrophy.

The mean values of TrA muscle thickness in elite female weightlifters were 3.38 and 3.11 mm in LBP and without LBP respectively. Several previous imaging studies have reported evidence of TrA muscle size in sedentary subjects [7, 13, 15, 79, 80, 93] and athletes [103, 104]. The mean TrA muscle thickness reported in this investigation was similar to the results reported previously [7, 79, 103, 105]. Mean TrA muscle thickness reported by Critchley and Coutts [13], Rankin et al [93] and Springer et al [80] were larger than the mean TrA muscle thickness reported in this investigation. One explanation might be that the subjects in those studies had larger mean body masses. Furthermore the position of image measurement may influence the thickness of TrA muscle [18]. Critchley and Coutts [13] measured abdominal muscle thickness of chronic LBP patients in four-point kneeling position. The muscle thickness may be larger by the effect of gravity.

The reduced TrA muscle thickness was reported in chronic LBP patients compared to healthy subjects during ADIM [13] . Also in study with experimentally induced pain demonstrated reduction of TrA muscle thickness during contraction and the percent change in muscle thickness [50]. The current study shows that the TrA muscle thickness during contraction is not different between elite female weightlifters with and without LBP. Whereas, CR of the TrA in LBP weightlifters are significantly lesser than weightlifters without LBP (*p*<0.001). Previous studies reported that the CR of TrA less than 2 in LBP patients [106-108] which is similar to the ratio in the current study (1.57 in LBP weightlifters). TrA contributes to segmental stability in lumbar spine [11, 94, 100]. The decrease in CR may be the reflecting the adaptation of TrA to pain or motor control dysfunction. Previous studies demonstrated greater activation of TrA after stabilization exercise [3, 5, 98, 102]. Therefore it may be suggested that specific stabilization exercises will be an appropriate intervention for LBP weightlifters. Further study is necessary to investigate the effect of specific stabilization exercise in weightlifters who suffer from LBP.

In conclusion, the results of this study revealed that elite female weightlifters showed no difference in thickness of TrA when compared with asymptomatic weightlifters. However the weightlifters with LBP exhibited significantly lesser contraction ratio of TrA than their counterparts.