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Impact of Rehabilitative Ultrasonography Imaging on Core Muscle Function in Patients with Visceral Adiposity: Randomized Controlled Trail

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Abstract: Background: Overweight is an excessive fat accumulation that may impair health. Visceral adiposity is one of the common causes of decreased endurance and strength of core stabilizing muscles, lumbar spine dysfunction and respiratory impairment. Consequently, this study aimed to determine the impact of rehabilitative ultrasonography imaging (RUSI) guided core muscle exercise, cavitation lipolysis and their combination on visceral fat thickness, waist circumference (WC), transverse abdominis (TrA) activation ratio, and diaphragmatic excursion in patients with visceral adiposity. **Methods:** forty-five patients diagnosed as overweight with localized abdominal visceral fat deposits, recruited from clinical nutrition unit, Elminya University Hospital. Patients age ranged from 25 to 45 years, body mass index (BMI) was 25-29.9 kg/m^2, WC was more than 102 cm for men and 88 cm for women and patients hadn't received lipolytic medications. They were divided randomly into three equal groups, Group (A) received RUSI guided core muscle exercise, group (B) received cavitation lipolysis and group (C) received RUSI core muscle exercise and cavitation lipolysis. Evaluation was done by ultrasonography imaging and tape measurement at the beginning and after 5 weeks. **Result:** There was a significant improvement in transverse abdominis activation ratio and diaphragmatic excursion in the three groups ($p<0.05$) as well as decrease in visceral fat thickness and WC in group B & C ($p < 0.05$), whereas, there is non-significant difference in group A ($p> 0.05$). **Conclusion**: Combination of RUSI guided core muscle exercise and cavitation lipolysis are effective approach in decreasing visceral fat thickness and WC, as well as improving transverse abdominis activation ratio and diaphragmatic excursion in patients with visceral adiposity.

Key Words: Visceral adiposity; Rehabilitative Ultrasonography imaging; Core muscle dysfunction; Cavitation lipolysis.

1 Introduction

Overweight and obesity, defined as abnormal or excessive fat accumulation that may impair health, constitutes a rising threat to public health and welfare and has become an epidemic in both developed and developing countries. It affects over 1.9 billion worldwide with (39%) adults aged eighteen years and older were overweight, of which, more than 650 million (13%) were obese [1].

Role of body composition should be considered, as emerging evidence suggests that fat and muscle mass have different roles in the musculoskeletal system dysfunction [2]. Expansion of adipose tissue in visceral region and increased waist circumference (WC) are considered a central element and pivotal sources in obesity related inflammation and some physical factors as lumbar spine dysfunction, muscle tightness, decrease muscle mass as well as decreased endurance and strength of core stabilizing muscles [3,4].

Transverse abdominis (TrA) muscle helps to compress the ribs and viscera, providing thoracic and pelvic stability. Improper contraction of the TrA muscle the nervous system can't recruit the muscles during extremities movement efficiently [5]. Overweight and obese people had a higher prevalence of weak abdominal muscles and forward shifted center of mass, which cause low back pain and delayed onset of deep abdominal muscles contraction than healthy people

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and resulting in more back muscle working to achieve balance [6].

Visceral adiposity significantly interferes with respiratory function due to the ineffectiveness of the diaphragm strength and resistance which lead to inspiratory overload, increases respiratory effort, oxygen consumption, and respiratory energy expenditure. Patients with diaphragmatic dysfunction can present with not only dyspnea on exertion but also sleep disordered breathing, decreased exercise performance, and impaired quality of life [7].

Rehabilitative ultrasonography imaging (RUSI) has been used in physical therapy practice as a procedure to evaluate muscle and related soft tissue morphology and function, also it can be used as guidance and feedback tool to show changes in muscle morphology during therapeutic interventions such as motor control exercises [8].

Trained physiotherapists perceived that imaging with ultrasound (US) provides the missing visual dimension used to improve rehabilitative and diagnostic capabilities, supporting the benefits of decision making in rehabilitation or even in direct access, as well as, providing biofeedback in the context of musculoskeletal and sports rehabilitation **[**9**]**.

Cavitation lipolysis is an additional useful physical therapy method in reducing visceral adiposity with lipolytic range of ultrasounds of 30-70 Kilohertz (KHz), and the best effects are obtained in a range between30-35 KHz. It affects fat cells through thermogenesis, which occurs because of cell absorption, and mechanical compression results in cavitation effect which destroys fat tissues **[**10**]**.

Aim: The purpose of this study is to determine the effect of RUSI guided core muscle exercise, cavitation lipolysis or their combination (RUSI guided core muscles exercise and cavitation lipolysis) on visceral fat thickness, WC, transverse abdominis activation ratio, and diaphragmatic excursion in patients with visceral adiposity.

2 Materials and Methods

2.1 Trial design

This trial was designed as a randomized controlled trial. The study was approved by the Ethical committee of Faculty of Physical Therapy, Cairo University (NO.P.T.REC/012/ 003449) and was registered on ClinicalTrials.gov with Identifier NO: (NCT05690659). This study complies with the Helsinki Declaration principles for human research. Each patient signed a written consent form after being given a thorough description of the trial. The study was conducted from December 2021 to October 2022.

2.2 Eligibility criteria:

Forty-five patients diagnosed as overweight with localized visceral abdominal fat deposits, recruited from clinical nutrition unit of Elminya university hospital, on the following criteria, both sexes participated in this study, their ages ranged from 25 to 45 years, their BMI was 25-29.9 kg/m^2, WC was more than 102 cm for men and 88 cm for women and subjects hadn't received lipolytic medications. . **(Fig 1).**

*2.3 Exclusion criteria***:**

A history of spinal surgery, spinal fracture or lumbar disc herniation, serious diseases such as heart disease, kidney, liver diseases, gastric ulcer or duodenal ulcer, history of bronchial asthma or any chest disease, uncontrolled diabetes or hypertension, patients with peacemaker or any metal implant on the treated area, cancer or patient with past history of tumor excision.

2.4 Evaluation procedures:

Patients were divided randomly into three equal groups, Group (A) received RUSI guided core muscle exercise, group (B) received cavitation lipolysis and group (C) received RUSI core muscle exercise and cavitation lipolysis. Evaluation of all groups were done before and after 10 sessions of treatment, 2 sessions/ week. **(Fig 1)**

2.4.1 **Assessment of Visceral Fat Thickness** Ultrasound imaging device (Mindary DP10, Curvilinear probe, with 5 MHz frequency, Serial number; bn-75013216, China) was used for evaluation of all patients. In supine position probe was positioned in transverse plane above umbilicus by 2 cm, distance was measured from lower border of abdominal muscle to upper border of pulsating aorta **[**11**].** Ultrasound imaging is a reliable, valid, and fast method for assessing both subcutaneous and visceral adipose compartments with excellent intraobserver and interobserver agreement, intraclass correlation coefficient (ICC) = 0.90–0.99, and fast ultrasound scan times of 95 ± 21 s for lean subjects and 129 ± 33 s for obese subjects **[**12**].). (Fig 2)**

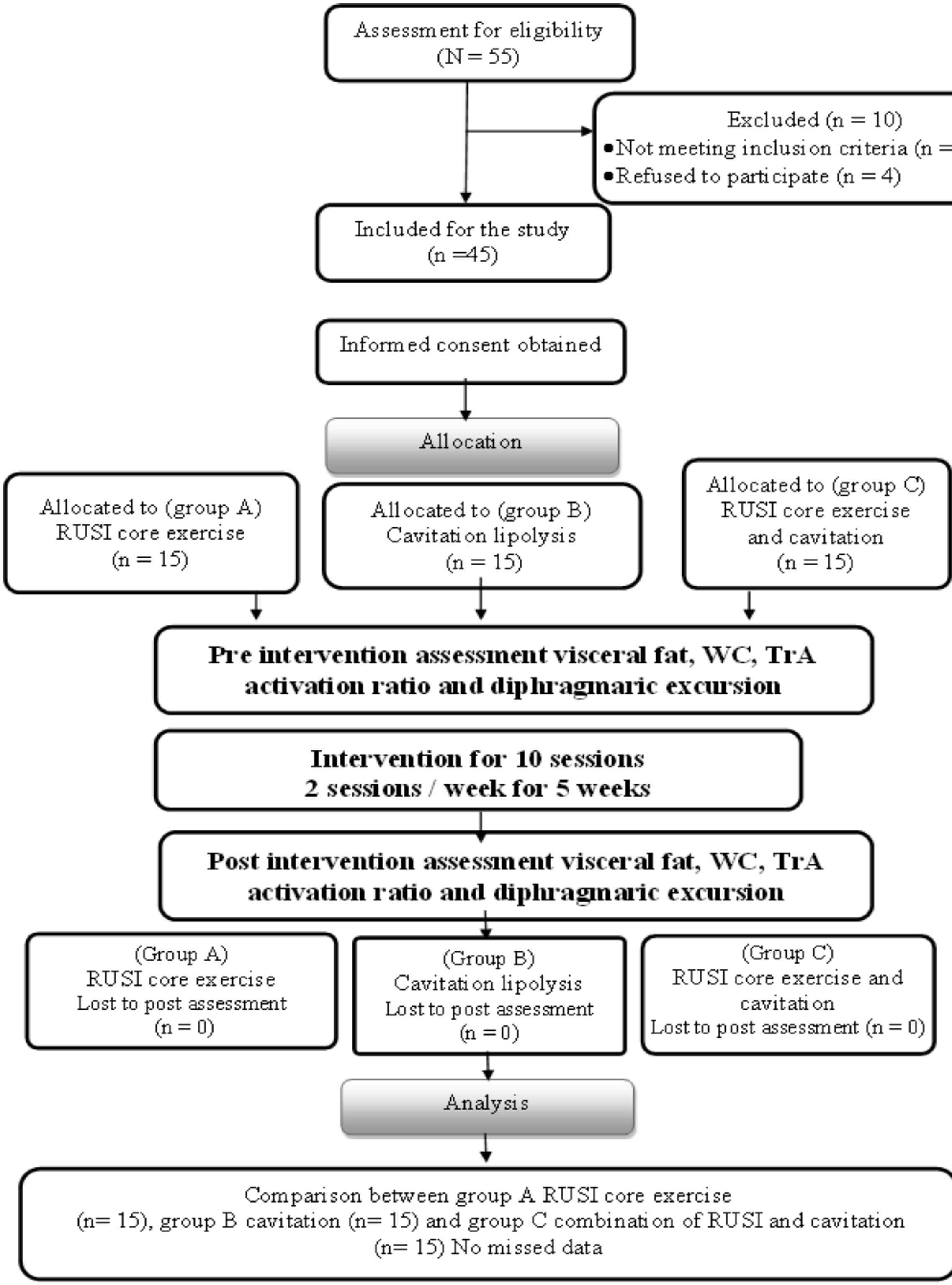

Fig . 1: Flow chart showing the experimental design of the study.

Fig. 2: US measurement of visceral fat thickness.

2.4.2 Assessment of Waist Circumference

By non-elastic, snug and 150-centimeter tape. Measurement was taken at the midway between lowest rib and the iliac crest. WC can be a predictable for central obesity where visceral adipose tissue is stored [13].

2.4.3 Assessment of Transverse Abdominis Activation Ratio

Ultrasound images were taken using 5 MHz curvilinear transducer from supine position. The transducer was placed in a transverse plane halfway between the anterior superior iliac spine (ASIS) and the lower ribcage along the anterior axillary line. The measurement of TrA activation ratio is taken from the lower border of internal obliques muscle to the inferior hyperechoic line of peritoneum at rest and during the abdominal drawing in maneuvers (ADIM) for all patients, then divided thickness during the ADIM by its resting thickness [14]. Intra image reliability for TrA contraction thickness and ratio was excellent: ICCs ranged from 0.95 to 1.00, the inter image reliability for absolute muscle thickness was moderate to high: ICCs ranged from 0.77 to 0.97 [15].

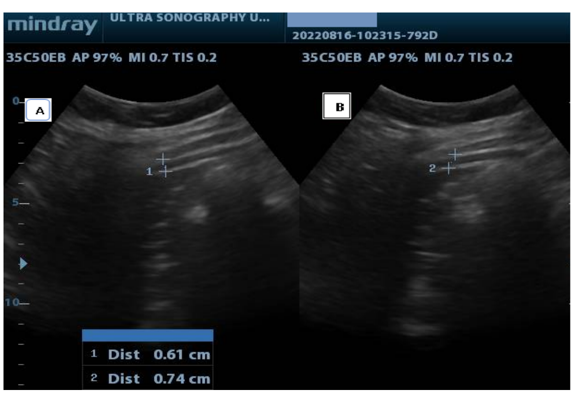

Fig. 3: US measurement of transverse abdominis activation ratio, (A) thickness at rest, (B) thickness at contraction

2.4.4 Assessment of Diaphragmatic Excursion

From supine position, M-mode US imaging 2.5-5 MHZ curvilinear transducer is used. The probe was placed between the mid clavicular and anterior axillary lines, below the right costal margin, and directed medially, cephalic and dorsally to pick up the posterior part of the right hemi diaphragm. The diaphragmatic excursion is measured by placing calipers at the bottom and top of the diaphragmatic inspiratory slope, all measurements were taken at the end of expiration phase [16].

Diaphragmatic excursion US is high temporal resolution, high reproducibility, and high accuracy, ICCs ranging from 0.876 to 0.99for intraobserver agreement and from 0.76 to 0.99 for interobserver agreement [17].

Fig. 4: US measurement of diaphragm excursion..

2.5 Treatment Procedures

The treatment in the three groups was done 2 sessions per week for 5 weeks.

2.5.1 RUSI guided diaphragm and TrA muscles exercise was administered to groups (A) and (C). The procedure was applied after applying 5-minute slide presentation in relaxed supine position. Each patient was instructed about sonoanatomy of the TrA and diaphragm muscles to get proper contraction performance of each muscle. The presentation was created to familiarize the patients with the RUSI and teach the patient how to regulate breathing during exercises [18]. For transverse abdominis exercise, ADIM is a fundamental motor control exercise used to preferentially activate TrA muscle contraction in comparison with the more superficial abdominal muscles. Patient instructed to “draw in your umbilicus toward the spine without moving back or pelvis and comfortably breathing in and out,” while seeing the changes of muscle thickness on the monitor of ultrasonography device as visual feedback in an attempt to maximize a targeted and continuous TrA contraction, for 10 seconds hold, then 15 seconds rest in between, it was repeated 3 sets of ten [19].

For diaphragm muscle the transducer was placed on the sub costal region to visualize diaphragm muscle on the screen aiming to use imaging with ultrasonography device as a xcomfortable supine position, instructed to have 5 seconds to contract the diaphragm muscle by deep breathing and hold the contraction for 5 second period, while keeping view the changes of muscle thickness on the ultrasound monitor to maximize a preferential of contraction. Each patient performed a total of 10 contractions (intervention session), as it was understood that more repetitions may induce fatigue. Twenty seconds of rest was provided between contractions [20].

Fig. 5: RUSI for (A) TrA, (B) Diaphragm muscles.

2.5.2 Cavitation lipolysis 40 MHZ, 150W/cm2 was performed for groups (B) and (C). Each patient was placed into supine lying position after evacuating bladder before session to ensure full relaxation. The abdominal region was covered by conductive gel, treatment head was griped perpendicular to the abdomen, and make slow circular motion with marked pressure for 40 minutes. The application of cavitation was applied 2 times a week for 10 sessions. Patients were suggested to drink at least 1.5-2 litres of water per day to stimulate the purifying action of liver and kidneys [21,22].

2.6 Statistical methods

Prior to analysis, the normality of data was checked using Shapiro-Wilk test. Levene's test for homogeneity of variances was conducted to test the homogeneity between groups. MANOVA test was conducted for comparison of subject characteristics between groups. Mixed MANOVA was performed to compare within and between groups effects on visceral fat thickness, WC, TrA activation ratio and diaphragm excursion. Post-hoc tests using the Bonferroni correction were carried out for subsequent multiple comparison. The level of significance for all statistical tests was set at $p<0.05$. All statistical analysis was conducted through the statistical package for social studies (SPSS) version 25 for windows (IBM SPSS, Chicago, IL, USA).

3 Results

3.1 Participant characteristics:

The mean±SD age (years) and BMI (kg/m²) of group (A, B and C) were, 38.13±3.94& 28.79±0.84, 37.33±5.49 & 29.22±0.37and 37.8±6.34 & 29.12±0.61 respectively. There was no significance difference between groups in age, BMI and sex distribution ($p>0.05$).

3.2 Effect of treatment on visceral fat thickness, WC, TrA activation ratio and diaphragm excursion:

Mixed MANOVA revealed that there was a significant interaction effect of treatment and time (Wilks' Lambda = 0.06, $F_{(8, 78)} = 29.28$, $p = 0.001$, partial eta squared = 0.75). There was a significant main effect time (Wilks' Lambda = 0.02, $F_{(4, 39)} = 478.55$, $p = 0.001$, partial eta squared = 0.98). There was a significant main effect of treatment (Wilks' Lambda = 0.62, $F_{(8,78)} = 2.59$, $p = 0.01$, partial eta squared = 0.22).

3.2.1 Within group comparison

There was a significant decrease in visceral fat thickness and WC in group B and C post treatment compared with that pretreatment (p<0.001). The percent of change of visceral fat thickness and WC in group B was 21.18 and 8.18% respectively and that in group C was 31.85 and 9.28% respectively. There was no significant change in visceral fat thickness and waist circumference in group A (p>0.05) (table 1).

There was a significant increase in TrA activation ratio and diaphragm excursion in the three groups post treatment compared with that pre-treatment (p=0.001). The percent of change in group A was 18. 1 and 33.33 % respectively, and in group B was 32.43 and 37.27% respectively, while in group C was 47.86 and 46.22 % respectively.

Between group comparison

There was a significant decrease in visceral fat thickness and WC of the group B & C compared to group A (p < 0.05). While, there was no significant difference in visceral fat thickness and WC between group B and C post treatment (p> 0.05).

There was a significant increase in TrA activation ratio and diaphragm excursion of the group C compared with that of group A and group B (p<0.05). There was no significant difference in diaphragm excursion and TrA activation ratio between group A and B (p>0.05). (Table 1).

Table 1. Mean visceral fat thickness, WC, TrA activation ratio and diaphragm excursion, pre and post treatment of group A, B and C:

	Group A	Group B	Group C	p-value		
	mean ± SD	**mean ± SD**	**mean ± SD**	**A vs B**	**A vs C**	**B vs C**
Visceral fat thickness (cm)						
Pre treatment	4.22 ± 0.53	4.25 ± 0.51	4.49 ± 0.62	1	0.52	0.71
Post treatment	4.07 ± 0.47	3.35 ± 0.61	3.06 ± 0.57	0.003	0.001	0.51
MD (% of change)	0.15 (3.55%)	0.9 (21.18%)	1.43 (31.85%)			
	p = 0.11	***p = 0.001***	***p = 0.001***			
WC(cm)						
Pre treatment	103.4 ± 5.72	105.86± 4.93	104.86± 5.51	0.65	1	1
Post treatment	102.53± 5.75	97.2 ± 4.26	95.13 ± 5.30	0.02	0.001	0.83
MD (% of change)	0.87 (0.84%)	8.66 (8.18%)	9.73 (9.28%)			
	p = 0.07	***p = 0.001***	***p = 0.001***			
TrA activation ratio						
Pre treatment	1.16 ± 0.2	1.11 ± 0.19	1.17 ± 0.13	1	1	0.9
Post treatment	1.37 ± 0.18	1.47 ± 0.22	1.73 ± 0.22	0.65	0.001	0.004
MD (% of change)	-0.21 (18.1%)	-0.36(32.43%)	-0.56(47.86%)			
	p = 0.001	***p = 0.001***	***p = 0.001***			
Diaphragm excursion (cm)						
Pre treatment	3.12 ± 0.39	3.22 ± 0.48	3.31 ± 0.52	1	0.83	1
Post treatment	4.16 ± 0.41	4.42 ± 0.34	4.84 ± 0.49	0.29	0.001	0.02
MD (% of change)	-1.04(33.33%)	-1.2(37.27%)	-1.53(46.22%)			
	p = 0.001	***p = 0.001***	***p = 0.001***			

SD, Standard deviation; p-value, Level of significance

4 Discussion

Owing to high BMI not only intimately associated with the prevalence of chronic low-grade inflammation, but also considered as the fourth leading risk factor worldwide for chronic diseases such as cardiovascular diseases (CVD), diabetes, non-alcoholic fatty liver disease (NAFLD) and certain types of cancer among other health complications [23].

Visceral but not subcutaneous adiposity was considered from the main determinants of both respiratory and spinal dysfunction as there was a significant association between visceral fat and impaired main respiratory functions, diaphragm and deep abdominal muscles functions [24].

According to the findings, there was a significant decrease in visceral fat thickness and WC after 10 sessions of treatment with cavitation lipolysis (group B) and when combined with RUSI core muscle exercise (group C) in patients with visceral adiposity ($p<0.05$). While there was no significant reduction in visceral fat thickness and WC after RUSI only (group A) ($p = 0.11$) ($p = 0.07$) respectively.

Also, our findings revealed that there was a significant increase in TrA activation ratio and diaphragm excursion post treatment compared with pretreatment in all groups ($p<0.05$). While group (C) showed more improvement in comparison to groups (A and B).

A possible explanation of the current results is that combined effect of RUSI core muscles exercise and cavitation lipolysis had a greater improvement for all measurement outcomes via both ideal recruitment of the TrA and diaphragm muscles achieved by RUSI guided training and potential lysis of visceral fat cells induced by cavitation lipolysis which reduce the direct mechanical effect of fat accumulation in the chest and abdominal regions, as it could significantly interfere with respiratory and spinal functions. No discomfort was reported during and after the treatment procedure, and no adverse events occurred during the course of the study.

Furthermore, **El-Gendy et al.** [25] found that cavitation lipolysis only is an effective procedure in reduction of abdominal fat thickness and WC in management of abdominal adiposity, as the cavitation can produce opening of the interstitial liquid triglycerides, this damage of the adipocytes results in an inflammatory response composed primarily of macrophages, neutrophils, and plasma cells attracted to engulf and transport the damaged cells and clear the destroyed adipocytes leading to a decrease in the local fat stores. This explanation is attributed to the improvement observed in groups B and C.

Also, **Taha et al.** [26] found that focused cavitation augmented with aerobic core exercise can be an effective noninvasive procedure for abdominal and liver fat reduction, as exercise could increase the lysing effect of cavitation by improving fatty acid metabolism, mitochondrial function, insulin resistance, and inflammatory cascades activation.

The current hypothesis was similar to that of **Henry et al** [27] who observed the slight decrease in lateral abdominal muscle thickness with simultaneous accumulation in intramuscular fat content in patients with abdominal obesity. Also, different literatures demonstrated the fact of decreased strength and mobility of the diaphragm and low physical performance which could be linked to visceral fat accumulation in obese individuals and can affect the diaphragmatic functions, allowing individuals with higher degrees of obesity may be more compromised functions [28,29].

The improved TrA activation ratio outcome is supported by **Zheng et al.** [30] who explained that training monitored by RUSI can markedly enhance TrA thickness and activation ratio much greater than the control group in healthy humans. RUSI is the key pattern for specific training to ensure the target muscle contracts in normal patterns and provides real time training feedback to participants and guarantee the correct training. Targeting deep core muscles as TrA mean that the activities of rectus abdominis and other abdominal muscle were not allowed and reduced compensatory motion, this improves the activation ratio of TrA in both sides than the control group.

Also **Huang et al.** [31] reveled that RUSI provide an effective method of core stability training for patients and specific monitoring training which facilitate selective control of the TrA independently on other abdominal muscles. Realtime ultrasound imaging has been validated as a type of metric to characterize the level of muscle activation, demonstrated that RUSI could measure activation of the TrA in a wide range 5-80% of maximal voluntary contraction. This provides evidence that muscle thickness change achieved by RUSI can be considered as a reliable indicator of muscle activation. RUSI could act as an advanced form of biofeedback to regulate the activation level of involved muscles.

The improvement was noticed in diaphragm excursion outcome could be explained by **Cho et al.,** [20] who found that the use of the RUSI for visual feedback plus verbal feedback for instructing how to contract the diaphragm muscle in healthy subjects is a beneficial training tool for consistent performance of the diaphragm compared to verbal feedback only which used in many clinics today, as RUSI can record changes in muscle thickness, fiber length, and cross sectional area and showing them at real time, RUSI has also been used for neuromuscular rehabilitation to enhance performance of isolated contraction of the deep muscles and beneficial motor learning process during recruitment of the deep muscle of the spine.

Also, **Marugán-Rubio** [32] found that diaphragm activation using visual feedback by RUSI in conjunction with inspiratory muscle training improved lung function by enhancing diaphragmatic thickness and excursion in athletes who suffered from non-specific low back pain. Increased forced expiratory volume (FEV_1) in these patients could be linked to greater chest wall expansion and could improve pulmonary function via core activation, as the FEV_1 reduction suggested an altered pulmonary function, core muscle dysfunction associated with LBP is a possible mechanism for this pulmonary impairment.

An attempt to confirm our result, **Trussardi et al.** [33] found that core muscle exercise didn't add any measurable benefit on the visceral fat and abdominal adipose tissue in obese individuals, but it's a beneficial method for improving muscle power.

In contrast to our findings, **Shek et al.** [34] who observed an abdominal circumference increase by 2.03 cm after three sessions of focused cavitation lipolysis treatment. This difference in their results may be due to measurement bias because of abdominal skin laxity after lipolysis.

Also **Reddy et al.** [35] concluded that the selected core muscle exercise intervention decreased the adipose tissue percentage of the badminton players and there was a significant effect on the adipose tissue thickness caused by improving core muscle strength. This contradiction may be due to application on professional athletes with proper muscle strength, while the current study was applied on obese participants.

The current study has some limitations, which are, Multifidus and pelvic floor muscles not included in the core muscle exercises. It is recommended that longitudinal studies to be applied with inclusion of all main core stabilizing muscles to explore the prolonged effect of RUSI guided core muscles exercise on visceral fat thickness and WC.

5 Conclusions

Combination of RUSI guided core muscle exercise and cavitation lipolysis are effective approach in decreasing visceral fat thickness and WC, as well as improving transverse abdominis activation ratio and diaphragmatic excursion in patients with visceral adiposity. RUSI guided core muscle exercise is an effective modality in improving transverse abdominis activation ratio and diaphragmatic excursion with no significant effect on visceral fat thickness and WC in patients with visceral adiposity.

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