ejpmr, 2016,3(4), 239-247

SJIF Impact Factor 3.628

EUROPEAN JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH

www.ejpmr.com

Research Article

ISSN 3294-3211

EJPMR

EFFICACY OF PILATE'S EXERCISE FOR STRENGTHENING OF DEEP ABDOMINAL MUSCLES IN ASYMPTOMATIC ADULT INDIVIDUALS

[1*]Prof. Chowdhury Shivani S., [2]Nishant Savani and [3]Prof. Sujata Yardi

[1]Professor and Head, Department of Electrotherapy and Electrodiagnosis, School of Physiotherapy, D.Y.Patil University, Nerul, Navi Mumbai.
[2]Physiotherapist, Surat;
[3]Advisor, School of Physiotherapy, D.Y.Patil University, Nerul, Navi Mumbai.

***Correspondence for Author: Prof. Chowdhury Shivani S.**

Professor and Head, Department of Electrotherapy and Electrodiagnosis, School of Physiotherapy, D.Y.Patil University, Nerul, Navi Mumbai.

Article Received on 29/01/2016 **Article Revised on 20/02/2016** **Article Accepted on 11/03/2016**

ABSTRACT

Background and Purpose: The aim of core stability training is to effectively recruit the trunk musculature and thereby learn to control the position of the lumbar spine during dynamic movements. This study was performed to study the effectiveness of Pilate's exercises in strengthening of deep abdominal muscles. **Methodology:** A randomised cross-sectional study was conducted to assess the efficacy of Pilates exercise regimes to increase the strength of the core stabilisers of the lumbar spine. 30 asymptomatic and apparently healthy individuals, without any history or known case of low back pain were randomly selected for Pilate's exercises. Subjects were explained the purpose of the study through and information sheet and consent for their participation was obtained before they enrolled for the exercise regime. The research study was conducted in Department of Physiotherapy, D.Y.Patil University, Nerul, Navi Mumbai. The Ethics Committee of Pad.Dr.D.Y.Patil University sanctioned the methodology. All the subjects were screened for low back problems using the *Oswestry Disability index*. Subjects having scored more than "0" on this scale were excluded from the study. *Lumbo-pelvic stability* was assessed by pressure biofeedback unit. (PBU). *Endurance testing* of the abdominals was conducted using a stop watch, and realtime *Ultrasound imaging* was used to assess muscle thickness of External oblique (EO), Internal oblique (IO) and Transverse abdominis (TrA) in supine lying and crook lying position. All the outcome measures were taken pre and post Pilates'exercise training sessions. All the subjects underwent a training session for 3days/week for 6weeks for introductory level of Pilate's exercise. **Results:** Statistical analysis was done using SPSS version 16.0 to comapare pre and post results in same group using paired t-test. Level of significance p- value < 0.05 was considered significant. A significant increase at $p<0.05$ was obtained in the measurements of "PBU" while performing lumbo- pelvic stability test in the crook lying position, both at rest and after TrA activation,. Thus indicating the ability to contract the abdominals by activating the TrA contraction, thereby activating the core mechanism improved after introductory level Pilate's training program. Highly significant result in endurance post Pilate's training program was obtained at $p<0.05$. Also, highly significant difference in the muscle thickness of EO, IO and TrA was noted at $p<0.05$. **Conclusion:** Pilate's training program is significantly effective in increasing strength of abdominal muscles and thereby improving lumbar spine stability.

KEYWORDS: Internal Oblique (IO), Extenal Abloque (EO), Transversus Abdominis (TrA) Lumbar Stabilization, Ultrasound Imaging, Pilates' Exercise, Abdominal Endurance.

INTRODUCTION

Nowadays abdominal exercises are becoming very popular. Everybody is concern about SIX-PACK abdominals for which they strengthen their rectus abdominis, external oblique, internal oblique and transverse abdominis. In which first two are mobilizers of trunk.[1] There are two group of abdominal muscles, one is 'mobilizers' and another is 'stabilizers'. If your stabilizers are strong, work of mobilizers reduces and also load on surrounding structure reduces. When mobilizers are working stabilizers support spine and help in precision of movement and prevent injury to spine and other structures[1]. The current vogue in physiotherapy and fitness training is to focus on what is known as 'core stability training, which specifically targets the smaller lumbar spine and deeper trunk muscles.

Core stability training aims at effectively recruiting the trunk musculature. Hodges and Richardson have described the lumbar spine area as 'inherently unstable'.[2] In practical terms, this means that the lumbar spine relies for stability on the muscles that actively support the area. Regardless of the philosophy underlying the different exercise programs, two of the key components for success are selection of exercises that best target the appropriate muscles and facilitate proper performance of

the exercise. Exercises that target the deep abdominal muscles with minimal external loading on the spine have been shown to be effective in increasing lumbar stability, thus treating and preventing the recurrence of low back pain (LBP).[3-11] The therapeutic application of exercise of the abdominal muscles is widely used in the management of LBP in order to provide this supplement to spinal stability. However, general exercise regimes have not succeeded in reducing LBP, and their physiological and practical foundations have been questioned [6]. Likewise, in a study conducted by Pintar et al.[12] it was ascertained that Traditional exercises do not have a significant impact on abdominal peak force in healthy young adult.

Pilates is a mind–body fitness program gaining in popularity and acceptance within the fitness community. Named after its founder, Joseph H. Pilates, and detailed in his publications (Pilates, 1934, 1945)[13,14], this fitness program incorporates the use of special apparatus and equipment into movement routines designed to enhance flexibility, strength, and coordination. Pilates is advocated as a beneficial exercise method in adult populations.[15-21]

Pilates is an exercise program as a core stability approach to augment the neuromuscular system to control and protect the core body or spine. This method is a comprehensive body-mind conditioning, which coordinates core stabilizing exercise with mind and breath control challenging by flowing movement of the whole body [18, 20]. Since a Pilates approach focuses on core body exercise and breath control, it facilitates activation of transversus abdominis, diaphragm, multifidus and pelvic floor muscles. Incorporation of these muscles contributes to stability of the lumbopelvic region. Pilates exercise has been claimed to be a successful program for health promotion, rehabilitation and athletic training. The study by Harrington and Davies supported that Pilate's method improved trunk control [23]. Regarding the benefits of Pilates for flexibility, the study by Kish [24] indicated that Pilates-based method significantly improved functional flexibility of the adductors and hip flexor muscles. However, the study by Wimer[25] showed that there was no change of flexibility after Pilates training in older adults. These study's findings require further investigation into its effective implication.

Also, studies in the past that have been carried out to assess the efficacy of abdominal exercises found effective results too. With good results there have been question on safety of conventional abdominals exercises with regards to the excessive, unsafe compressive forces on lumbar spine structure and intervertebral disc, which could pose a risk acquiring lumbar spine problem like prolapsed intervertebral disc. Hence it was warranted to formulate newer and safer strengthening exercises for the abdominal muscles along with the stability of the lumbar spine posture. Thus the importance core stabilizers and its strengthening through Pilates' exercises made way into physiotherapy rehabilitation armoury. So far, there have been limited reports on the therapeutic effects of Pilates training on increasing the strength of the abdominal musculature using lumbo-pelvic stability, endurance and changes in muscle thickness as outcomes. Hence we carried out a randomised cross-sectional study to assess the efficacy of Pilates exercise regime for strengthening of deep abdominal muscles in normal asymptomatic adult individuals.

MATERIALS AND METHODOLOGY

Figure-1: PBU to assess lumbo-pelvic stability.

A randomised cross-sectional study was conducted over a period of one year, to study the efficacy of Pilates exercise regimes to increase the strength of the core stabilisers of the lumbar spine. 30 asymptomatic adults between 18 years and 25 years, BMI <25 and apparently healthy individuals, without any history or known case of low back pain were randomly selected for Pilate's exercises. Subjects with a history of Back pain, spinal surgery, spinal tumors, spinal deformity, neurological problems and/or any cardiovascular problems were excluded from the study. Subjects were explained the purpose of the study through and information sheet and consent for their participation was obtained before they enrolled for the exercise regime. The research study was conducted in Department of Physiotherapy, D.Y.Patil University, Nerul, Navi Mumbai. The methodology of the study was sanctioned by the Ethics Committee of Pad.Dr.D.Y.Patil University. All the subjects were screened for back disability using the Oswestry Scale prior to recruitment for the study. Subjects with an index score of more than '0' were excluded from the study.

Lumbo-pelvic stability using pressure-pelvic stability biofeedback unit (PBU) (Chattanooga Group, Inc). The testing procedure followed the Harrington and Davies [23] and Jull et al[26] *(Refer Figure 1).* It was measured using grades given by Richardson and Jull as pressure in mm of mercury (Hg). First measurement was taken in crook lying position after TrA activation than all four grades: level 1a, level 2b, level 2a, and level 2b were noted in mmHg. If a subject is not able to hold TrA contraction in level 1a next levels were not checked.

Endurance of abdominal muscles was measured by counting the repetition of movement in one minute performed by individual. For endurance testing stopwatch was used. Ultrasound imaging of the three deep abdominal muscles: External oblique, Internal oblique and Transverse abdominis was measured in mm by sonologist with the use of laboratory ultrasound imaging technique. Six different measurements were taken on each subject in supine lying and crook lying position for EO, IO, TrA muscle. The positions used for recordings were supine lying at rest, supine lying hollowing manoeuvre, crook lying at rest, crook lying hollowing manoeuvre, crook lying hollowing manoeuvre with heel slide and crook lying hollowing manoeuvre going back to starting position.

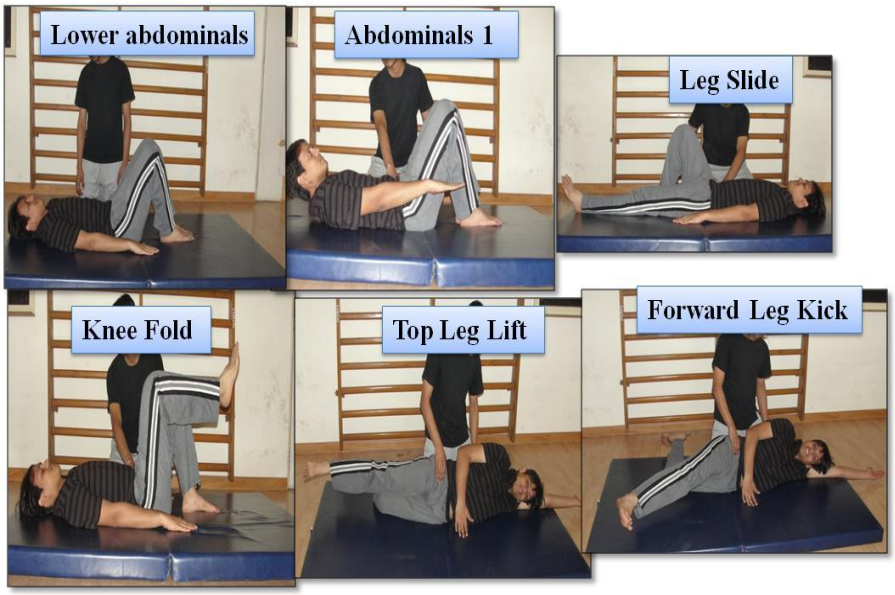


Figure 2: Exercises done during training

All subjects were trained for 3days/week for 6weeks for introductory level of Pilate's exercise. All the candidates were assessed twice during entire experiment. They were divided into six groups. Five subjects in each group. Subjects were explained principle of Pilate's and importance of TrA activation prior to training program and continue with normal breathing in first week. In the same week subjects were trained how to activate TrA muscle and self palpation of the same was taught for one week. Also, they were trained to make pelvis in neutral position which they have to maintain during exercise. Subjects were trained by five different exercises for 6 weeks. These were Lower abdominals 1, Abdominals 1, Leg slide; Knee fold; Forward leg kick and Top leg lift *(Refer Figure 2)*. Subjects were made to lie-down on the jumbo mat to perform exercises, in well lighted and ventilated hall. All exercises were done in steps. In all of them instructions were given and supervised by therapist in each exercises.

RESULTS

Statistical analysis was done by biostatistician using SPSS version 16.0 to compare pre and post results in same group we have used paired t-test. Level of significance p- value < 0.05 was considered significant. Demographic details of the 30 subjects who included in the study are as shown in Table-1.

Table-1: Demographic distribution of subjects recruited in the study.

Age group	Pilate's exercise	
	Male Subjects	**Female subjects**
18	0	3
19	2	5
20	0	1
21	0	1
22	0	7
23	0	2
24	2	4
25	1	2
Total	**5**	25
Total sample size- **n**	**30**	

Lumbo-pelvic stability

The results of the study showed that was a statistically significant difference between the pre and post values of PBU which in-turn shows significant result in maintaining dynamic stability of spine tested during level 1a of grading.

Table -2 depicts the t values and significance of PBU values at baseline, pre and post training of TrA muscle and Level 1a of training.

Table-2: Comparison of Pressure biofeedback unit values pre and post Pilates training

PBU		Mean	Std. Deviation	t	Sig. (2-tailed)
Rest	Pre	4.0	0		
	Post	4.0	0		
TrA	Pre	46.3333	2.10637	11.609	0 Highly significant
	Post	42.4	0.81368		
Level 1a	Pre	21.7333	3.74104	24.531	0 Highly significant
	Post	37.4667	0.89955		

Significant increase obtained in the measurements of PBU while performing lumbo-pelvic stability test in the crook lying position, indicates improved ability to contract the abdominals by activating the TrA contraction, there by activating the core mechanism improved after introductory level Pilate's training program both at rest and after TrA activation[17]. Statistically significant increase was noted in further levels of the lumbo-pelvic stability test 1a comprising of heel slide of one leg with other leg stabilized on the plinth.

Thus indicating an improvement in the ability to contract abdominals at the same time maintaining lumbo pelvic stability post Pilate's training program.

Realtime Ultrasonography

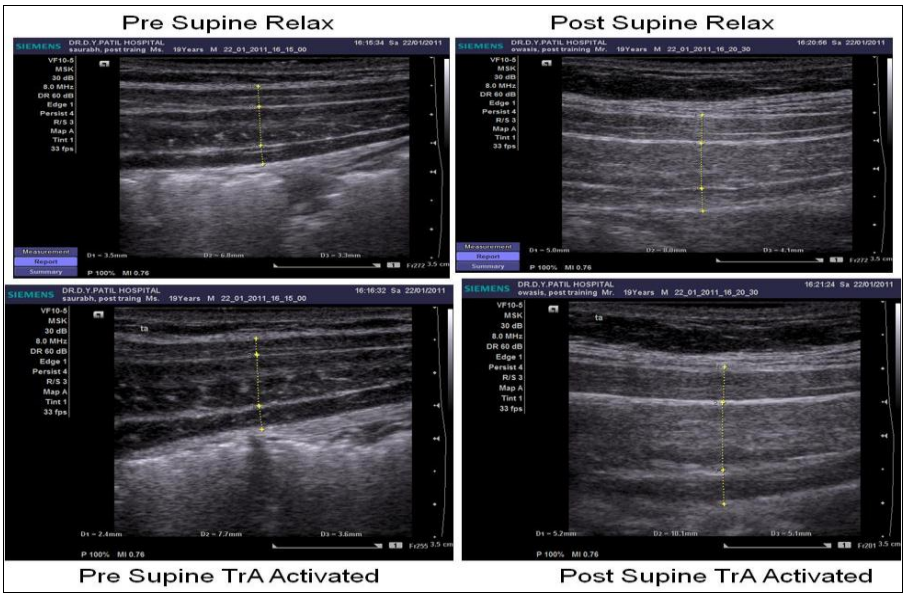
Ultrasonographic measurements were obtained using a by a sonologist; in collaboration with the radiology department. The technique used has been previously described in studies conducted in the past.[27,28,29,30] The values were consistent with the previous technique [14]. The six measurements in mm of three muscle thickness taken in supine position at rest and during abdominal drawing in manoeuvre showed significant changes in thickness of TrA, IO, EO muscle. (Refer Figure -3 and Table -2a)

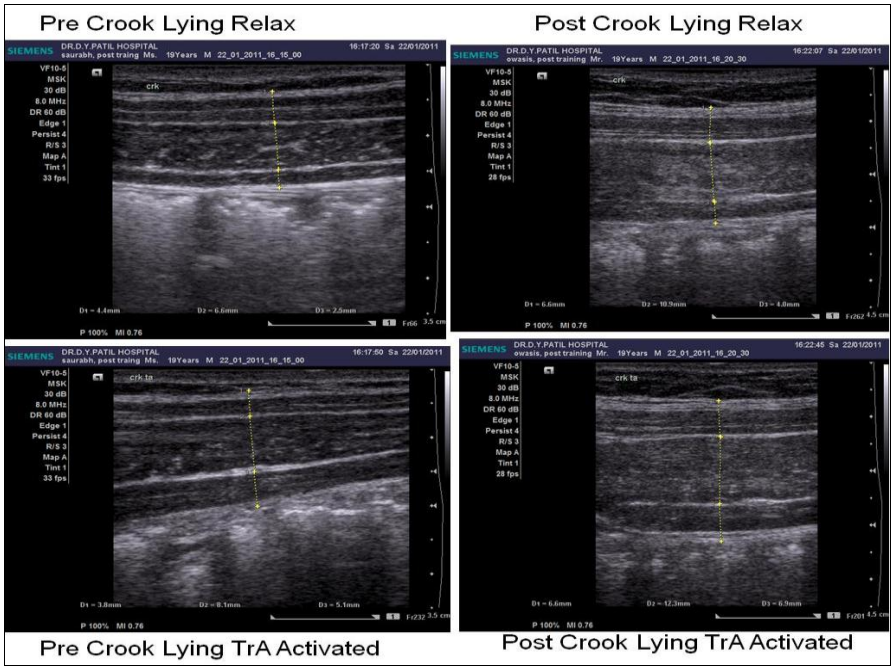
Statistically significant increase was observed in all the muscle thickness of TrA, IO & EO On the contrary, statistically increase in the muscle thickness of IO and TrA only was obtained during 1a level of the lumbo-pelvic stability test. We found greater changes in the muscle thickness of the internal oblique as compared to TrA not only at rest but also after activation, contrary to the findings of many researchers who claimed to advocate that the abdominal drawing in manoeuvre is based on the ability to preferentially to activate TrA.

Table 2a- Comparison of measurement of muscle thickness of external obliques, Internal obliques and transverses abdominis; pre and post Pilates exercise regime

USG Position			*Mean*	*Std. Deviation*	*t*	*Sig. (2-tailed)*
Supine Relax	EO	Pre	4.0633	1.02972	4.032	0 Highly Significant
		Post	4.6833	0.61928		
	IO	Pre	5.54	1.12299	5.69	0 Highly Significant
		Post	6.78	1.64262		
	TrA	Pre	3.2467	0.64044	9.968	0 Highly Significant
		Post	4.0833	0.70422		
Supine Hollow In	EO	Pre	3.09	0.7448	8.324	0 Highly Significant
		Post	4.4433	0.66316		
	IO	Pre	7.12	2.50192	3.203	0.003 Highly Significant
		Post	8.1633	2.12578		
	TrA	Pre	4.7367	0.87197	4.987	0 Highly Significant
		Post	5.6733	0.97766		
Crook Lying Relax	EO	Pre	4.26	0.80101	4.269	0 Highly Significant
		Post	5.07	1.07516		
	IO	Pre	5.82	1.44327	8.621	0 Highly Significant
		Post	8.4367	1.60032		
	TrA	Pre	3.3933	0.82334	4.739	0 Highly Significant
		Post	4.3133	0.76597		
Crook	EO	Pre	4.0867	1.06859	2.455	0.02

Lying Hollow In		Post	4.4933	0.88666		Not Significant
	IO	Pre	7.6233	1.58955	3.248	0.003 Highly Significant
		Post	9.0333	2.33479		
	TrA	Pre	4.63	0.84492	7.293	0 Highly Significant
		Post	6.15	1.14914		
Crook Lying Heel Slide	EO	Pre	4.1067	0.93548	1.879	0.07 Not Significant
	IO	Post	4.4567	1.2381		
		Pre	7.4067	1.52518	3.774	0.001 Highly Significant
		Post	8.5467	1.92224		
	TrA	Pre	4.24	0.6072	9.864	0 Highly Significant
		Post	6.87	1.3689		
Crook Lying Starting Position	EO	Pre	4.11	1.02431	0.869	0.392 Not Significant
		Post	4.2967	1.0012		
	IO	Pre	7.2167	1.45864	5.9	0 Highly Significant
		Post	8.67	1.97295		
	TrA	Pre	4.5733	0.80727	8.732	0 Highly Significant
		Post	6.8733	1.55296		





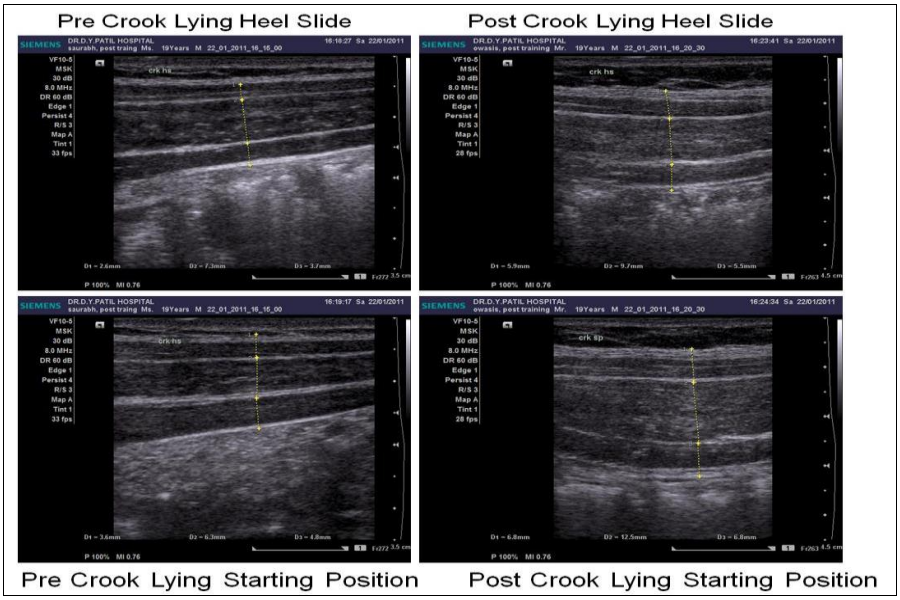


Figure-3: Ultasounography images of changes of muscle thickness in different positions.

Table -3: Comparison of endurance of abdominal muscles pre and post Pilate's exercise regime.

		Mean	Std. Deviation	t	Sig. (2-tailed)
Endurance	Pre	28.4667	2.62262	29.894	**0** **Highly Significant**
	Post	40.5	2.54274		

Muscle Endurance

Statistical significance of endurance suggested *(Refer Table -3)* that Pilate's training program also improves endurance of the abdominal muscles

DISCUSSION

PBU changes demonstrated that Pilate's trained subjects could activate TrA effectively. PBU measurements also demonstrated that Pilate's training program is significantly effective in increasing strength of abdominal muscles and thereby improving lumbar spine stability.

Ultrasound imaging ascertained the effectiveness of Pilate's training in increasing the thickness of the abdominal muscles like EO, IO & TrA when measured at rest and during drawing in maneuver in supine and crook lying position. However, it is also evident that dynamic stability of the spine during heel slide did not recruit EO as compare to that of IO and TrA in term of muscle thickness. Statically significant changes of abdominal muscle endurance suggested that Pilate's training program also improves endurance of the abdominal muscles.

The results of this study suggest that Pilate's method can be used as an adjunctive exercise program for improving abdominal muscle recruitment, encouraging control-mobility of trunk and pelvic segments. It may also help in preventing and attenuating the injury and dysfunction of musculoskeletal system.

Therefore, it can be stated that Pilate's training program is significantly effective in increasing strength of abdominal muscles and thereby improving lumbar spine stability.

In current study, we hypothesized the paramount benefits of Pilate's exercises regime for physiological functions "whether Pilates-based conditioning significantly improves the strength of deep abdominal muscles in normal asymptomatic adult individuals"; measured as changes in PBU readings, USG changes in muscle thickness and changes in the endurance of abdominal muscles following a 6-week exercise programme. The results of the present study demonstrated that the lumbo-pelvic stability, muscle thickness and endurance significantly improved in the experimental group. These results are similar to those with previous studies.[23,24,31]

Lumbo-pelvic stability

Logical explanations for improvement of lumbo-pelvic control are relevant to specific concepts of Pialte's exercise in terms of the role and neural control mechanism of local muscles, motor learning and physiological response to specific volume of Pilate's program. The concept of Pilates exercise focuses on core or powerhouse and breath control that activates local muscles, especially transversus abdominis, internal oblique, diaphragm, lumbar multifidus and pelvic floor muscles. Currently, scientific data show that these muscles have primary role in stabilizing the lumbo-pelvic system [32, 33, 34]. The stability of lumbo-pelvic system is also dependent on the central nervous system to determine the requirements of stability by pre-

programmed TrA contraction to stabilize the spine prior to trunk perturbation from limbs movement and external load to the body's parts [31]. Using Pilate's exercises may lead to CNS enhancing the control of the spine when the trunk is challenged by internal and external forces (e.g., as a result of the reactive forces from moving upper and lower limbs during each position of exercise).

Considering motor leaning described by Magill [35], it can be implied into: 1) Cognitive stage; the participants paid attention to cognitive oriented problem needed high awareness in order to isolate TrA contraction during each position of practices, using the verbal cues including internal and external feedback to detect errors, and followed the instructor step by step. 2) Associative stage; participants learned to associate some environmental cues with the movements by minimizing errors and perform consistently control contraction of TrA when the movement is challenged.

Participants could detect errors and correct them themselves. Once association took place, the new movement sequence might become automatic. The volume of Pilates exercise in this study was specific to cause physiological effects. Prolonged exercise (approximately 45 minutes) with low to moderate intensity is specific to promote strength, endurance, and neuromuscular control of the local muscles (i.e., transversus abdominis, pelvic floor and multifidus muscles).[36] The local muscle largely consists of type I or slow-twist skeletal muscles. Type I fibers contain plentiful mitochondria, high amount of oxidative enzymes and high density of capillaries. These characteristics make them well adapted for endurance activities over 30 minutes such as Pilates exercise prescription in this trial. Size or crosssectional area of type I muscles increase as a result of increasing mitochondria, membranous and muscle filaments within the fibers.[37] Thereby, the strength and endurance of type I fibers occur showing improvement of lumbo-pelvic stability. Improved recruitment and synchronous stimulation of these motor units also account for increased muscle strength.[36,38]

In th present study there was a significant increase obtained in the measurements of PBU while performing lumbo- pelvic stability test in the crook lying position, both at rest and after TrA activation,. Thus indicating the ability to contract the abdominals by activating the TrA contraction, there by activating the core mechanism improved after introductory level Pilate's training program. The above mentioned activity is recruited as a part of introductory level Pilate's exercises which is the first step to Pilate's training program. A study done by Lee Harrington and R. Davis[23], ascertained that lumbo-pelvic stability test required a good lumbo-pelvic control. However 100% of the subjects in our study demonstrated poor lumbo-pelvic control prior to the Pilate's training. Thus this indicates that deep abdominal muscles may not get optimally recruited. A previous study performed by Jull et al[26] proposed a prerequisite ability to perform an abdominal setting action which enhanced the subject automatic muscle support through a learning effect. Therefore, due to Pilate's exercise, it was mandatory that a subject has prerequisite to ability to perform this manoeuvre thereby causing a motor learning effect to carry out a further exercise regime effectively.

The lack in facilitating a correct TrA contraction proposes that asymptomatic individuals may have a difficulty in gaining a perception to the required contraction; this indicates a dysfunction in automatic motor control stability.[23] Therefore all subjects included in Pilate's training program needed to learn correct TrA contraction in order to achieve lumbo-pelvic stability.

Statistically significant increase was noted in further levels of the lumbo-pelvic stability test 1a comprising of heel slide of one leg with other leg stabilized on the plinth. Further indicating an improvement in the ability to contract abdominals at the same time maintain lumbo-pelvic stability post Pilate's training program. All the subjects could neither complete 1a level nor proceed further in performing the lumbo-pelvic stability test.

Ultrasound Imaging

Findings of the present study are in agreement to findings of C.M. Norris.[1] Who ascertained the role of EO, IO, TrA as stabilizers of trunk movement. He categorized abdominals as primary and secondary stabilizers. The primary stabilizers are those muscles which cannot create significant joint movements, such as the multifidus and transversus abdominis. These muscles act only to stabilize. The secondary stabilizers, such as the internal oblique, have excellent stabilizing capacity, but may also move joints.[7]

Consecutively statistical significant increase was observed in IO and TrA muscle thickness while performing TrA activation in the crook lying position. On the contrary statistically increase in the muscle thickness of IO and TrA only was obtained during heel slide depicting the 1a level of the lumbo pelvic stability test we found greater changes in the muscle thickness of the internal oblique as compared to TrA not only at rest but also after activation, contrary to the findings of many researchers who claimed to advocate that the abdominal drawing in maneuver is based on the ability to preferentially to activate TrA.[28] There was no significant change in the thickness of EO while performing the same. This is in agreement with the Teyhen et al.[7]; which ascertain that EO muscle thickness is not associated with changes in the muscle activation. Similar observation were seen in ultrasound imaging measurements of 3 muscles while the limb was taken back to the starting position post Pilate's training program again indicating an improvement in the recruitment of the muscles which strengthen with the Pilate's training program.

There is a negative relationship between increase in muscle thickness and ability to stabilize spine as measured by PBU during isometric contraction of abdominal muscles. Thus indicating that as the thickness of the muscle increases there is a subsequent decrease in drop of pressure in mmHg readings on the PBU. There by signifying the improvement in lumbo-pelvic stability in post Pilate's training program.

The subjects were asked to fill the Oswestry Disability Index (ODI) post Pilate's training to rule out for any form of disability or pain after the exercise regime. All the subjects scored ODI of "0" again, thus indicating no pain or disability post exercise program. On the contrary a few subjects mentioned about feeling of tightening of their abdominals and increased spinal support post exercise regime.

Based on the above study further studies can be undertaken in patient population to ascertain the effects of Pilate's exercises in reducing symptoms and improving lumbar spine stability.

Past research studies utilizing Pilates finds support for the effectiveness of Pilates in asymptomatic adults to improve flexibility, transversus abdominis activation, lumbar–pelvic stability, and muscular activity.[39] Well-designed experimental studies that randomize subjects, utilize a control group, define the Pilate's method utilized, calculate statistical power and sample size, and using valid and reliable methods to measure outcomes, would build a body of scientific evidence of Pilates' efficacy and effectiveness in practice with healthy adults.

CONCLUSION

Pilate's training program can be used effectively in increasing strength of abdominal muscles and thereby improving lumbar spine stability.

REFERENCES

1. C.M.Norris, Functional load abdominal training part 1,Journal of bodywork and movement therapies, July 1999.
2. Hodges Ja, Richardson CA, Jull. GA. Inefficient muscular stabilization of the lumbar spine associated with low back pain: A motor control evaluation. Spine, 21: 2640-2650
3. van Tulder, M., Koes, B., Bouter, L., Conservative treatment of acute and chronic non-specific low back pain, Spine, 1997; 22(18): 2128–2156.
4. Crisco, J., Panjabi, M., The intersegmental and multisegmental muscles of the lumbar spine. Spine, 1991; 16(7): 793–799.
5. O'Sullivan, P., Twomey, L., Allison, G., Altered abdominal muscle recruitment in patients with chronic back pain following a specific exercise intervention. Journal of Sports Physical Therapy, 1998; 27(2): 114–124.
6. Koes, B., Bouter, L., Beckerman, H., Van Der Heijden, G., Knipschild, P., Physiotherapy exercises and back pain: a blinded review. British Medical Journal, 1991; 302: 1572–1576.
7. Teyhen DS, Rieger JL, Westrick RB, Miller AC, Molloy JM, Childs JD, Changes in deep abdominal muscle thickness during common trunk-strengthening exercises using ultrasound imaging. J Orthop Sports Phys Ther., Oct, 2008; 38(10): 596-605.
8. Axler CT, McGill SM. Low back loads over a variety of abdominal exercises: searching for the safest abdominal challenge. Med Sci Sports Exerc, 1997; 29: 804-811.
9. Karst GM, Willett GM. Effects of specific exercise instructions on abdominal muscle activity during trunk curl exercises. J Orthop Sports Phys Ther, 2004; 34: 4-12. http://dx.doi.org/10.2519/jospt.2004.1145
10. Richardson CA, Jull GA. Muscle control-pain control. What exercises would you prescribe? Man Ther, 1995; 1: 2-10. http://dx.doi.org/10.1054/math, 1995; 0243.
11. Shirado O, Ito T, Kaneda K, Strax TE. Electromyographic analysis of four techniques for isometric trunk muscle exercises. Arch Phys Med Rehabil, 1995; 76: 225-229.
12. Pintar, JA, Learman, KE, and Rogers, R. Traditional exercises do not have a significant impact on abdominal peak force in healthy young adults. J. Strength Cond. Res., 2009; 23(7): 2083-2089.
13. Pilates, J., 1934. Your Health. Presentation Dynamics Inc., Incline Village, NV.
14. Pilates, J., 1945. Return to life Through Contrology. Presentation Dynamics Inc., Incline Village, NV.
15. Reyneke, D., The Pilates method of exercise and rehabilitation. Physiotherapy in Sport, 1993; 18(3): 19.
16. LaBrusciano, G., Lonergan, S., Pilates: a method ahead of its time. Strength and Conditioning August, 74–75.
17. Latey, P., 2001. The Pilates method: history and philosophy. Journal of Bodywork and Movement Therapies, 1996; 5(4): 275–282.
18. Latey, P., Updating the principles of the Pilates method— part 2. Journal of Bodywork and Movement Therapies, 2002; 6(2): 94–101.
19. Stanko, E., The role of modified Pilates in women's health Physiotherapists in Women's Health, 2002; 90: 21–32.
20. Muscolino, J., Cipriani, S., Pilates and the ''powerhouse''—I. Journal of Bodywork and Movement Therapies, 2003a; 8: 15–24.
21. Muscolino, J., Cipriani, S., 2003b. Pilates and the ''powerhouse''— II. Journal of Bodywork and Movement Therapies, 2003b; 8: 122–130.
22. Smith, K., Smith, E., Integrating Pilates-based core strengthening into older adult fitness programs. Topics in Geriatric Rehabilitation, 2004; 21(1): 57–67.
23. Harrington L, Davies R. The influence of Pilates training on the ability to contract the Transversus

abdominis muscle in asymptomatic individuals. J Body Work Mov Ther., 2005; 9: 52-7.
24. Kish R. The Functional Effects of Pilates Training on Dancers. PhD thesis. California State University; Department of Kinesiology, 1998.
25. Wimer J. The effects of functional resistance training on muscular strength, balance and functional abilities of older adults. PhD thesis. San Diego State University; Department of Exercise and Nutritional Sciences, 1999.
26. Jull G, Richardson C, Toppenberg R, et al. Towards a measurement of active muscle control for lumbar stabilization. Aus J Physiother, 1993; 39: 187-93.
27. Springer BA, Mielcarek BJ, Nesfield TK, Teyhen DS. Relationships among lateral abdominal muscles, gender, body mass index, and hand dominance. J Orthop Sports Phys Ther, 2006; 36: 289-297. http://dx.doi.org/10.2519/jospt.2006.2217
28. Teyhen DS, Miltenberger CE, Deiters HM, et al. The use of ultrasound imaging of the abdominal drawing-in maneuver in subjects with low back pain. J Orthop Sports Phys Ther, 2005; 35: 346-355. http://dx.doi.org/10.2519/jospt.2005.1780
29. Teyhen DS, Gill NW, Whittaker JL, Henry SM, Hides JA, Hodges P. Rehabilitative ultrasound imaging of the abdominal muscles J. Orthop Sports Phys Ther., 2007; 37: 450-466
30. Whittaker JL, Teyhen DS, Elliott JM, et al. Rehabilitative ultrasound imaging: understanding the technology and its applications. J Orthop Sports Phys Ther.,, 2007; 37: 434-449. http://dx.doi.org/10.2519/jospt.2007.2530
31. Segal A, Neil H, Basford R. The effects of Pilates training on Flexibility and body composition: An observational study. Arch Phys Med Rehab, 2004; 85: 1977-81.
32. Hodges PW. Changes in motor planning of feed-forward postural responses of the trunk muscles in low back pain. Exp Brain Res., 2001; 141: 261-6.
33. Vasseljen O, Fladmark AM. Abdominal muscle contraction thickness and function after specific and general exercises: A randomized controlled trial in chronic low back pain patients. Man Ther, 2010; 15: 482-9.
34. Critchley D. Instructing pelvic floor contraction facilitates transversus abdominis thickness increase during low-abdominal hollowing. Physiother Res Inter, 2002; 7: 65-75.
35. Magill R. Motor Learning Concepts and Applications: The Stage of Learning. 6 ed. Boston: McGraw-Hill. 2001.
36. Richardson C, Hodges PW, Hides J. Therapeutic Exercise for Spinal Segmental Stabilization in Low Back Pain: Scientific Basis and Clinical Approach. Edinburgh: Churchill Living Stone, 2004.
37. McArdle WD, Katch FI, Katch VL. Exercise Physiology: Energy, Nutrition, and Human Performance. 6 ed. Philadephia: Lippincott Williams & Wilkins, 2007.
38. Liemohn W. Exercise Prescription and the Back. New York: McGraw-Hill, 2001.
39. Lisa Marie Bernardo, The effectiveness of Pilates training in healthy adults: An appraisal of the research literature, Journal of Bodywork and Movement Therapies, 2007; 11: 106–110.