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CORRELATION BETWEEN TRANSVERSUS ABDOMINIS MUSCLE ENDURANCE AND LIMITS OF STABILITY IN ASYMPTOMATIC HEALTHY YOUNG WOMEN

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ABSTRACT

Background: All tasks require postural control. The appropriateness and adequacy of postural tone in the trunk muscles referred to as "Core muscles" is the key element for the control of normal postural stability in an erect position. From among the core muscles (local and global), Transversus Abdominis muscle is controlled independently of the other trunk muscles and its activation is associated with postural demand. The study aims to assess the TrA muscle endurance and Limits of Stability (Maximum Excursion-MXE and Directional Control-DC) and to determine the correlation between the two parameters.

Methods: A Correlation study was performed on 100 asymptomatic healthy nulliparous urban women of 18-25 years' age with Body Mass Index of 18.5- 27.9 kg/m^2. Participants performed two tests in random order; Prone Test for TrA muscle endurance using Pressure Biofeedback Unit and LOS Test using the NeuroCom Balance Manager®. The outcome measures were TrA endurance (Number of 10 seconds hold) and MXE (%) and DC (%) of the LOS test.

Results: Mean (mean ± SD) values were TrA endurance: 4.93 ± 3.31, Maximum Excursion (%): 92.8 ± 7.69 and Directional Control (%): 84.53 ± 3.17. Results showed a significant positive correlation between TrA endurance and MXE whereas no significant correlation was observed between TrA endurance and DC (Pearson's correlation test; r=0.201 and r= -0.084, respectively at $p<0.05$).

Conclusion: Transversus Abdominis muscle endurance has a significant role in controlling the equilibrium (stability) component of the Postural Control but does not play a significant role in the orientation component.

Keywords: Transversus abdominis muscle, Core muscles, Balance, Limits of stability, Muscle endurance, Pressure biofeedback unit, NeuroCom Balance Manager.

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INTRODUCTION

All tasks require postural control. Postural Control involves controlling the body's position in space. It is a complex skill based on the interaction of dynamic sensorimotor processes and is required for dual purposes of stability and orientation. That is, every task has an orientation component and a stability component. However, with every task and the environment, the stability and orientation requirements vary [1,2].

"Postural Orientation" is defined as the ability to maintain an appropriate relationship between the body segments, and between the body and the environment for a task. Most functional tasks require a vertical orientation of the body for which we use multiple systems for sensory references including the vestibular system, the somatosensory system, and the visual system. In other words, we depend on gravity, the interrelationship of different body segments, the relationship of our body to the support surface, and the relationship of our body to objects in our environment [1].

"Postural Stability" also referred to as Balance, is the ability to control the projected center of mass within the limits of the base of support [1].

Balance control involves the interaction of the musculoskeletal, neurological and contextual factors (Figure 1) [3]. Every individual has a distinctive set of constraints and resources from the various systems that are at hand for postural control. Thus, postural performance is context specific depending upon the demands of the task [2].

Horak et al. (2006) [2] postulated a multisystem model describing the important resources for Postural Control (Figure 2). Considering the biomechanical constraints to postural control under this model, Stability Limits form an important part of balance control system involving the control of body's Centre of Mass concerning Base of Support (BOS) [2].

Figure 1: Interactions of the musculoskeletal and nervous systems and contextual effects for balance control

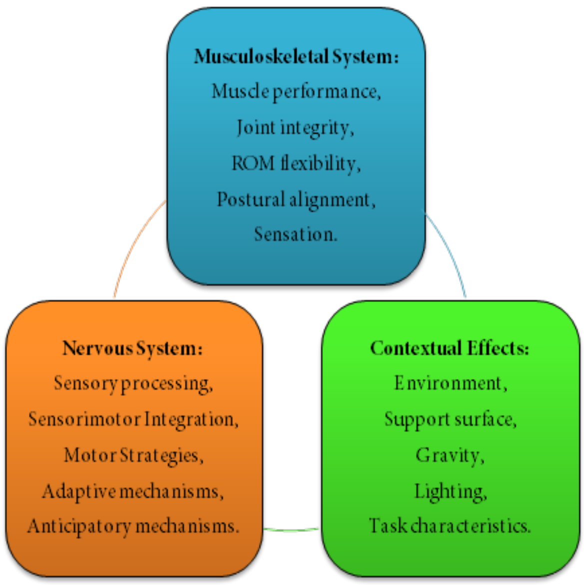
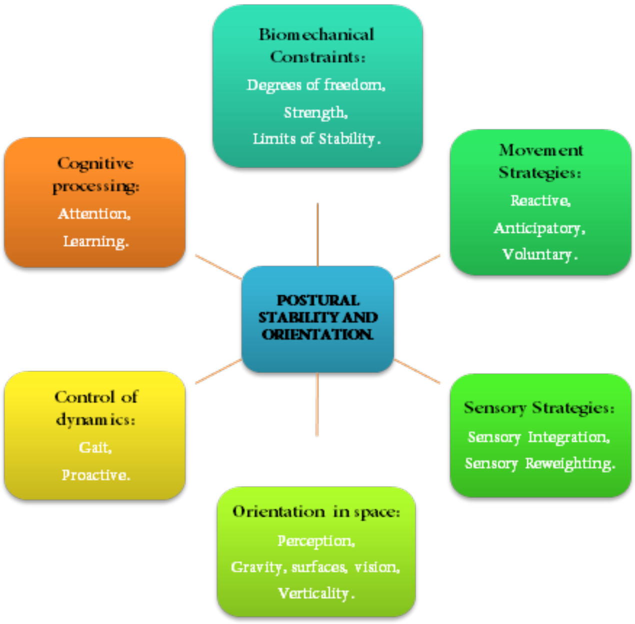


Figure 2: Resources for Postural Stability and Orientation



"Limits of Stability" refers to the sway boundaries in which an individual can maintain equilibrium without changing his or her BOS. These constantly changing boundaries are dependent on the task, the individual's biomechanical factors such as muscle strength, the range of motion at the joint, characteristics of the COM and aspects of the environment [1, 3].

Functional Stability Limits can be defined as the percentage of the base of support that individuals are willing to extend their center of pressure (COP). COP is the point of application of ground reaction forces under the feet. The inertial forces of the body along with restorative forces that maintain postural equilibrium together produce the center of pressure. The displacement of this pressure point provides information regarding the biomechanical and neurological mechanisms of postural control [4].

Gravity, muscle activities, co-activities, interactions between body segments during motion, or unpredictable perturbations like a push, a trip or a collision tend to disturb the balance in day to day life [1]. When the COG falls outside the BOS, the structure becomes unstable and falls, or some force must act to keep the structure upright [3].

It is suggested that postural tone in the trunk segment is the key element for control of normal postural stability in the erect position. Appropriate activation of abdominal and other trunk muscles often discussed "core stability" is important for efficient postural control [1].

Core Stability is the ability of the neuromusculoskeletal system to maintain or resume an upright position of the trunk in the presence of disturbances. Within this definition, stabilizing the core is a dynamic process of maintaining balance [5].

During an integrated kinetic activity, core stability ensures appropriate production, transfer, and control of force and motion to the terminal segment [6].

The muscles of the trunk segment can be categorised into two systems: the outer global system comprising of the superficial muscles: Rectus Abdominis (RA), External Oblique (EO), Internal Oblique (IO), lateral portion of

Quadratus Lumborum (QL) Erector Spinae (ES) and Iliopsoas and deep local system comprising of the deeper muscles: Transversus Abdominis (TrA), Multifidus (MF), deep portion of the Quadratus Lumborum (QL) and deep rotators of the spine. The integrated and coordinated activity of both the systems ensures that the stability is maintained during varying movements and postural demands (Bergmark). The superficial global muscles produce and control the movement of the trunk while generating larger torques and to also respond to external loading of the vertebrae in a direction specific manner to control the spinal orientation. The deep local muscles control segmental motion by working as segmental guy wires [7, 8, 9].

The Transversus Abdominis (TrA) is the deepest of all abdominal muscles and responds uniquely to postural perturbations contributing to spinal stability differently [8,10,11]. Due to the transverse orientation of the TrA muscle fibers, it's activation directly does not produce any significant torque on the trunk [10]. As the TrA activates, the lower abdominal wall is drawn in, and abdominal circumference reduces provided the displacement of the abdominal contents prevented by the diaphragm and the pelvic floor muscles [11]. This creates tension in the thoracolumbar fascia (TLF) and results in increased intra-abdominal pressure (IAP) and hence greater spinal stability [12].

The TrA is predicted to activate in anticipation of any disturbances caused by the rapid arm or leg movements or during spinal loading before the activation of other abdominal muscles [8, 13, 14]. Also, TrA is activated in non-direction specific manner [10, 14, 15]. This anticipatory activity regardless of the direction provides evidence that CNS controls the TrA separately [8,10,11,13,14].

As all the back muscles consist of a greater percentage of type 1 fibres than type 2, a certain proprioceptive function is apparent and hence plays a crucial role in postural and stabilization functions [8]. To protect the inert, passive structures of the lumbar spine, the trunk muscles may require maintaining optimal levels of activation for long periods of time rather than with maximum strength [16]. Hence, TrA muscle endurance may play a better role than its strength in maintaining postural stability.

The ability to control our body's position in space is fundamental to everything we do [1]. Balance is a very important aspect of our everyday lives as it is required in various day to day activities which in turn require postural control.

Many studies in literature, considering varying populations have attempted to establish correlations between various trunk muscles and balance. These studies are largely therapeutic or rehabilitative or intervention based [17, 18, 19, 20, 21, 22]. Most of these studies have emphasized on core muscle strength whereas the role of endurance in balance has not been clear. Literature has identified a certain relationship between core muscles performance and balance and postural control [10, 11, 17, 18, 23, 24] but the results of these studies are variable owing to methodological differences in assessment of the outcome variables.

The COP being an approximation of the COG under static or slow moving conditions COP shifts is a common variable used to assess the boundaries of the stability. Browne and Hare (2001) suggested that force platform measurements appear to be most appropriate as it provides a real-time display as well as is capable of detecting small changes in subject's balance ability [25].

A Pressure Biofeedback Unit (PBU) is a useful tool to test the TrA function and has acceptable clinical usage [26, 27, 28].

Hence, the primary objective of the present study was to study the correlation between Transversus Abdominis muscle endurance and Limits of Stability, a measure of dynamic stability, in healthy asymptomatic women.

Thus, it was hypothesized that there could be a correlation between Transversus Abdominis muscle endurance and Limits of Stability – Maximum Excursion and Directional Control.

MATERIALS AND METHODS

A correlation type of study was conducted on a convenience sample of 100 subjects drawn from tertiary care center and college within 12 months of study duration.

- Asymptomatic healthy nulliparous urban women of 18 to 25 years of age within Body Mass Index of 18.5 to 27.9 kg/m^2 [29] (Scale 1) were included, whereas regular exercising or undergoing training in any form of exercises, recreational or professional sports playing individuals were excluded from the study.

Scale 1: Obesity Grades, Indian Standards

RANGE (kg/m^2)	GRADE
<18.5	Underweight
18.5 - 22.9	Normal
23 - 27.9	Overweight
28 - 32.9	Grade 1 Obesity
33 - 37.9	Grade 2 Obesity
38 and >	Grade 3 Obesity

Sit and Reach testing box, Measure Tape, and Weighing Scale were used for baseline assessment (Figure 3). Pressure Biofeedback Unit (Stabilizer™, Chattanooga) was used to assess Transversus Abdominis muscle endurance (Figure 4) and Neurocom Balance Manager®; Version 8.6 was used to assess Limits of Stability (Figure 5).

Figure 3: Materials used for baseline measurements (Sit and Reach Box, Weighing Scale, Measuring Tape)

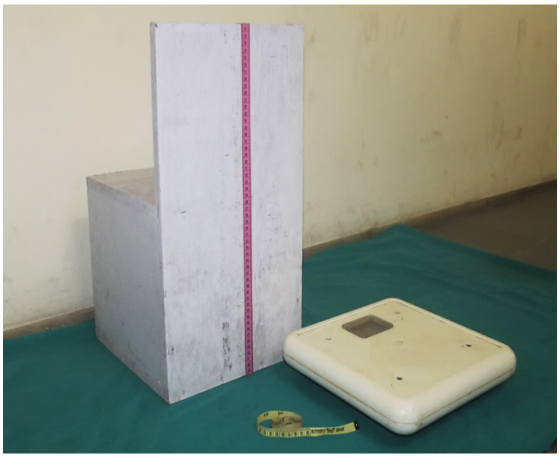


Figure 4: Pressure Biofeedback Unit, Stabilizer™

Figure 5: NeuroCom Balance Manager®

METHODOLOGY

Study design and the study were approved by the Ethical committee. Purpose and the procedure of the study were explained to the subjects, and they were screened according to the inclusion and exclusion criteria. Written consent was taken from all the participants.

Baseline screening criteria included assessment of Body Mass Index grade, Indian Standards (Scale 1) and Modified Sit and Reach Test Ratings for lower back and lower limb flexibility (Scale 2).

Scale 2: Modified Sit and Reach Test Ratings

Range (cm)	Rating for women ≤ 35 years of age.
> 17.9	Excellent
16.7 – 17.9	Good
16.2 – 16.7	Average
15.8 – 16.2	Fair
<15.4	Poor

A Convenience sample of 100 subjects was enrolled in the study. Subjects included were assessed for Transversus Abdominis (TrA) muscle endurance and Limits of Stability (LOS) in random order using odd-even number method to control for order effect. Odd numbered subjects were made to perform TrA test first and Even numbered subjects were made to perform LOS test first, followed by the second test respectively.

TRANSVERSUS ABDOMINIS MUSCLE ENDURANCE [PRONE TEST]: (Figure 6) [30, 31, 32].

Test Procedure:

- The subject was made to lie prone, and the Stabilizer™ Pressure, Biofeedback Unit cuff, was placed horizontally under the abdomen with navel at the center of the unit. The lower edge of the cuff lies just below the anterior superior iliac spines (ASIS).
- The pressure cuff was inflated to 70 mmHg, and the subject was instructed to perform the drawing-in maneuver while fully relaxing the abdomen and maintaining relaxed breathing without moving the spine or pelvis
- If done properly, the pressure dropped by 6 to 10 mmHg.
- The subject was asked to try and maintain the pressure drop (drawing in) for up to 10 seconds.

A 20 sec break was given between each contraction (10sec hold).

Muscle endurance (holding or tonic capacity) of the Transversus Abdominis (TrA) was measured by the number of 10-second holds (up to 10).

Figure 6: Prone test for Transversus Abdominis

LIMITS OF STABILITY: [USING NEUROCOM BALANCE MANAGER®, Version 8.6] :(Figure 7) [33, 34].

The Limits of stability test quantifies the maximum distance that a person leans as fast as he/she can towards the target in a given direction after the "start" cue without loss of balance, stepping or reaching in any direction for assistance. The computer screen displays eight targets at 45° angles (front, sides, back and four diagonal points).

- The subject had to follow visual cues and move his/her body accordingly to hit targets identified on the computer screen.
- The eight peripheral targets are sequentially highlighted in a clockwise direction, and the subject was asked to move towards the highlighted target by leaning the body about the ankle joint in the identified direction.
- The subject was asked to provide maximum range but without trick movement patterns.

Composite values were taken for five parameters measured for weight shifts in 8 directions.

Parameters of Maximum Excursion and Directional Control were taken into consideration.

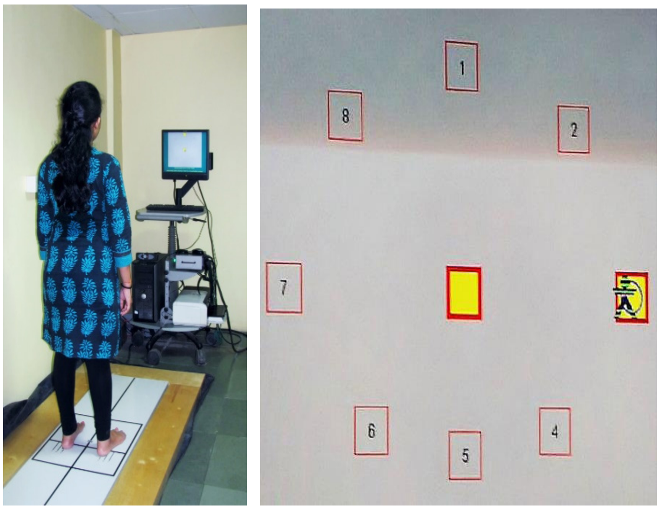
- **Maximum Excursion (%)** – the greatest distance reached by the center of pressure towards the target during the entire trial period. It is expressed as a percentage of a straight line from center to the target.
- **Directional Control (%)** is a ratio of the distance of a straight line from center to target to the total distance

that the subject moved. Deviation from a straight path will increase the total distance moved. Directional control is given as a percentage, with a higher percentage showing better directional control.

The outcome measures considered for statistical analysis were:

1. Transversus Abdominis muscle endurance (number of 10 seconds hold).
2. Maximum Excursion (%).
3. Directional Control (%).

Figure 7: Subject performing the Limits of Stability Test



RESULTS AND ANALYSIS: Data Analysis: The data were entered using Microsoft Office 2010 and analyzed using Statistical Package for Social Sciences (SPSS) version 20 and Primer of Biostatistics software.

The numerical data were analyzed for normality using the One – Sample Kolmogorov – Smirnov Test. Demographic data, as well as the study variables – Transversus Abdominis muscle endurance, Maximum Excursion and Directional Control, were normally distributed. Pearson's Correlation Test was used for correlation analysis of the variables with a p-value less than 0.05 considered as statistically significant.

A significant positive correlation was observed between TrA Endurance and Maximum Excursion

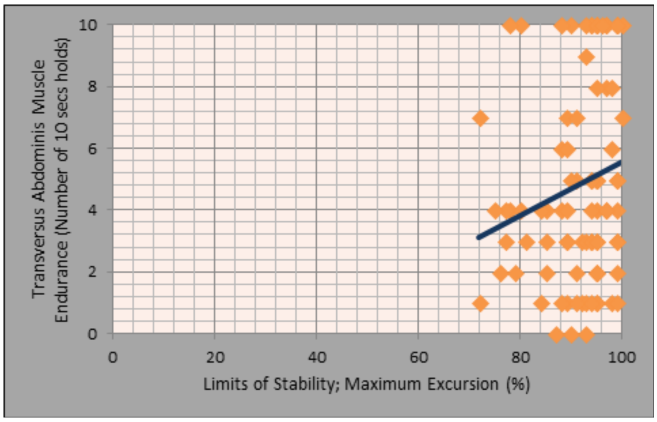
($r = 0.201$, $p = 0.045$). (Table 1, Graph 1)

A negative correlation was observed between TrA Endurance and Directional Control, but this correlation did not reach statistical significance ($r = -0.084$, $p = 0.408$) (Table 1, Graph 2).

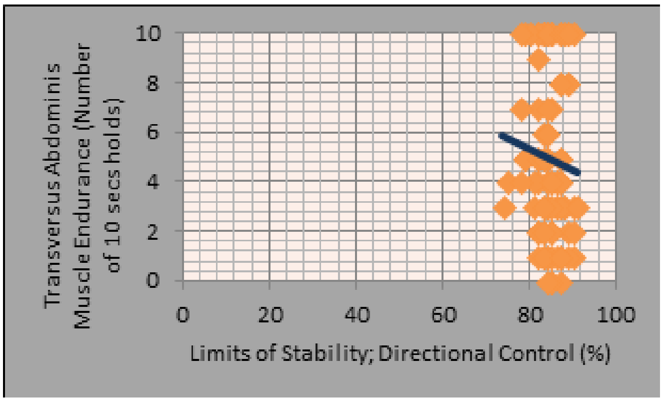
Table 1: Correlation between Transversus Abdominis muscle endurance and Limits of Stability

Correlation	Correlation Co-efficient	p-value	Significance
Correlation between **TrA endurance and Maximum Excursion**	r = 0.201	0.045	Correlation is **significant** ($p<0.05$)
Correlation between **TrA endurance and Directional Control**	r = - 0.084	0.408	Correlation is **not significant** ($p<0.05$)

Graph 1: Scatter Plot representing the Correlation between TrA Endurance and Maximum Excursion



Graph 2: Correlation between TrA Endurance and Directional Control



DISCUSSION

The biomechanics of the trunk region is different in females as compared to the males owing to variation in the anatomy [35]. Davis and Marras (2000) [12] identified that gender and anthropometry (height, weight, body composition) constitute a part of the secondary factors that influence the trunk motion and biomechanics. Since females exhibit smaller cross-sectional areas, they have smaller moment-arms and hence lesser force generating capacity for most of the trunk muscles [36]. In the context of expected loads to the spine, females are closer to the thresholds of tolerance or the strength capacity and therefore are at an increased risk of injury [37].

The thickness of the TrA as compared to the total lateral abdominal muscles at rest and during Abdominal Drawing in Manoeuvre (ADIM) is on an average greater in women by 5% and 6%, respectively. Hence, it suggests that women may be able to contract TrA better than men as the muscle proportion is greater. This possibly explains the differences in neuromuscular control between the genders [38].

BMI has a positive correlation with the lateral abdominal muscles' thickness. Muscle fibre composition is similar in both genders however males and persons with higher Body Mass Index probably have larger fibre size and greater isokinetic strength. It is also seen that males exhibit greater fatigability of the lumbar paraspinal muscles than females, although the rate of change of fatigue status is dependent on BMI irrespective of the gender [38].

Thus, the above literature suggests that gender and BMI could be secondary influences over `activation of the TrA.

Hence, in the present study, to maintain the homogeneity of the sample and to control for possible gender and BMI influences the sample characteristics were predetermined as mentioned in the screening criteria for the inclusion or exclusion of the participant.

Main findings of the study were:

There is a significant positive correlation between Transversus Abdominis muscle endurance and Maximum Excursion of the Limits of Stability. ($r = 0.201$ and $p = 0.045$) (Graph no.1).

There is no significant correlation between Transversus Abdominis muscle endurance and Directional Control of the Limits of Stability. ($r = -0.084$, $p = 0.408$) (Graph no.2).

The correlational observations identified in the present study support the previous studies done by Crommert (2011) [10], Tsukhagoshi, Shima, Nakase et al. (2011) [24] and Cetin, Bayramoglu, Aytar et al. (2008) [39].

Postural Control is a complex sensorimotor skill. The two main functional goals of postural control are postural orientation and postural equilibrium [2].

The structural loading factors for postural stability include the biomechanical factors such as Intra-abdominal Pressure (IAP), muscles activated, the various imposed moments on the trunk and the actual amount of loads on the spinal structures [12].

The biomechanical model proposed by Cholewicki and Van Vliet (2000) [40] states that under a particular situation, the function of a single muscle depends on various factors which include the orientation of the muscle fibres, the lever-arm length and the neural activation [10].

Owing to the transverse orientation of TrA muscle fibres, bilateral contraction of TrA purely produces drawing-in of the lower abdominal wall and does not produce any significant torque on the spine. Hence, TrA does not require compensatory co-activations of other trunk muscles to balance the trunk [10, 38, 41].

The TLF provides increased inter-segmental stiffness by the generation of lateral tension which is required for stability of the vertebral column. The tensile forces are transferred more efficiently to the TLF via the tension that develops in the direction of TrA muscle fibres simulating its contraction than tension in IO and EO. The IAP needs to be elevated to create a significant tension impact on the TLF, which is done effectively by the TrA and to some extent by IO, EO, and RA. This IAP mechanism maintains the integrity of the abdominal muscles and reduces the loading on the spine as the TLF assists in the generation of an extensor moment [12].

However, Hodges (2003) [42] suggested that rather than the development of spinal stiffness for stability, controlled mobility that is dynamic stability is clinically more advantageous and important. TrA activation facilitates this control.

The muscle co-activation produced as a result of increased trunk motions is a consequence of well-defined programming of the various neurological pathways controlling the muscles [12]. The CNS coordinates the response of these muscles to bring about the precise movement required for the specific task [8]. Every individual adopts a preferred motion strategy while performing any exertion which leads to specific co-activation and recruitment patterns resulting from past experiences of similar type. These programs are constantly updated and are fine-tuned through experience [12]. Every voluntary movement involves pre-planned motor programming by the CNS which in turn makes adjustments in anticipation to offset the impact of the predicted perturbations and to maintain the steady alignment of the different body segments [10].

Evidence regarding the fact that CNS controls the TrA separately is replete [8, 10, 11, 38]. Hodges (1999) [38], through his review on evidence of TrA in lumbopelvic stability, suggested that TrA is activated irrespective of the preparatory, non-preparatory or wrong preparatory responses [[8, 10, 11, 38].

Crommert (2011) [10] studied the effect of varying direction and magnitude of the imposed moments on the spine and found that direction did not affect the level of TrA activation whereas larger the magnitude, greater was the TrA activation. He also concluded that TrA was activated in a non-specific direction manner and hence CNS may be controlling it separately from the other trunk muscles. This indicates that the activation of TrA is pre-programmed by the central nervous system (CNS) contributing to the preparation of the spine in anticipation of expected perturbations [11].

Hodges (1999) [11] in an attempt to develop a model of the contribution of the TrA to spinal stability suggested that the superficial muscles Rectus Abdominis, Internal Oblique, External Oblique and Erector Spinae (RA, IO, EO and ES) through their co-activity control the orientation of the spine as well as the COM. The TrA does not control the spinal orientation. He also identified that although Multifidus (MF) and TrA are the inter-segmental stabilizers of the spine, MF is direction specific whereas TrA is non-direction specific. Above studies [10, 11, 43] strengthen the role of TrA as a controller of the stabilizing forces on the spine and hence protects the spine from imposed moments on an inter-segmental level, irrespective of the direction.

Tonic low-level activation of TrA has also been reported in subjects in standing position [14]. Hence, TrA plays a dual role in standing, one to keep the upright trunk posture in balance and second to counteract the imposed demands on the trunk. It is observed that in the absence of postural demands the early onset of TrA activation is unnecessary and the activation of TrA co-varies with the degree of imposed postural demands on the trunk. Hence, it can be concluded that TrA is facilitated when postural demands increase and thus may play a role in maintaining the postural stability when the Centre of Gravity (COG) of the body and hence the Centre of Pressure (COP) is challenged [10, 14].

Pickerill and Harter (2011) [34] quoted Nashner and McCollum's definition of Dynamic Postural Stability as the ability to shift and control the COG within a fixed Base of Support (BOS) wherein the BOS refers to both the foot position and surface condition remaining stationary. Functional Stability Limits can be defined as the percentage of the BOS that individuals are willing to extend their COP [1, 34].

Biomechanically, it is imperative that the spine is controlled optimally to ensure the right amount of stability at any given time. Also, stability is a prerequisite that enables the spine to bear loads, permit movements and simultaneously provides a base for extremity movements [10]. The tonic activity of TrA fulfills this requirement of adequate stability of the spine efficiently [8].

Thus, from the above literature following conclusions can be drawn:

1. The maximum distance reached by the center of pressure towards the target is referred to as the **Maximum Excursion** [33]. With the appropriate stabilization of the spine and in the absence of other range limiting factors greater dynamic postural stability can be achieved and **greater dynamic balance implies greater Stability Limits** [2, 5, 10, 11, 33].
2. **Directional Control (DCL)** is a comparison of the amount of movement towards the target to the amount of movement away from the target. In other words, it is the comparison between the amount of intended to amount of extraneous movement and thus is a measure of spinal orientation [33]. **The activation of TrA is not related to the direction of trunk movement or the direction of displacement of the COM** [10, 14, 43]. Thus, TrA being an inter-segmental stabilizer does not control the orientation of spine.

CONCLUSION

Transversus Abdominis being the deep tonic inter-segmental stabilizer of the spine, its endurance is expected to play a role in the maintenance of spinal stability that is required for Limits of Stability of an individual. Hence, it can be concluded that Transversus Abdominis muscle endurance has a significant role in controlling the equilibrium (stability) component of the Postural Control but does not play a significant role in the orientation component.

The results of the present study can be utilized as baseline references for normal values of Transversus Abdominis muscle endurance and Limits of Stability for asymptomatic healthy young Indian women. Also from the study, it can be clinically applied that assessment and development of protocols for improving musculoskeletal fitness levels of healthy asymptomatic individuals as well as for rehabilitation protocols for prevention of back pain must consider the positive correlation between Postural stability and Transversus Abdominis muscle endurance. Due to the correlation type of study, the cause and effect relationship between the variables could not be concluded but a similar study can be carried out to study the same as well as to analyse the effect of training Transversus Abdominis muscle on balance in asymptomatic subjects as well as in subjects with low back pain as it is the principle muscle affected in these subjects.

Randomization was not performed for selection of the samples, and emotional and motivational status during the test was not considered, were few limitations of the study. A multicentric study with larger sample size and considering gender differences could be carried out. Future studies could consider better methodological aspects such as utilizing Ultrasonographic Imaging or Fine Wire Electromyography to study the tonic activity of the Transversus Abdominis concurrently while performing the Limits of Stability test.

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Disclaimer

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