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The Role of Core Stability in Athletic Function

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Abstract

The importance of function of the central core of the body for stabilisation and force generation in all sports activities is being increasingly recognised. 'Core stability' is seen as being pivotal for efficient biomechanical function to maximise force generation and minimise joint loads in all types of activities ranging from running to throwing. However, there is less clarity about what exactly constitutes 'the core', either anatomically or physiologically, and physical evaluation of core function is also variable.

'Core stability' is defined as the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer and control of force and motion to the terminal segment in integrated athletic activities. Core muscle activity is best understood as the pre-programmed integration of local, single-joint muscles and multi-joint muscles to provide stability and produce motion. This results in proximal stability for distal mobility, a proximal to distal patterning of generation of force, and the creation of interactive moments that move and protect distal joints. Evaluation of the core should be dynamic, and include evaluation of the specific functions (trunk control over the planted leg) and directions of motions (three-planar activity). Rehabilitation should include the restoring of the core itself, but also include the core as the base for extremity function.

1. What is the Core?

The musculoskeletal core of the body includes the spine, hips and pelvis, proximal lower limb and abdominal structures. The core musculature includes the muscles of the trunk and pelvis that are responsible for the maintenance of stability of the spine and pelvis and help in the generation and transfer of energy from large to small body parts during many sports activities.[1,2] The muscles and joints of the hip, pelvis and spine are centrally located to be able to perform many of the stabilising functions that the body will require in order for the distal segments (e.g. the limbs) to do their specific function, providing the proximal stability for the distal mobility and function of the limbs. In addition to its local functions of stability and force generation, core activity is involved with almost all extremity activities such as running, kicking and throwing. Therefore, the position, motion and contributions of the core must be evaluated and treated as part of the evaluation and treatment of extremity injuries.

This article provides a general functional definition of core stability, describes the anatomy and physiology of core muscles, discusses core stability in function and dysfunction, provides principles of clinical evaluation of core stability, and describes rehabilitation and conditioning programmes to maximise the effect of core stability on athletic function.

2. Definition of Core Stability

Core stability is an important component maximising efficient athletic function. Function is most often produced by the kinetic chain, the coordinated, sequenced activation of body segments that places the distal segment in the optimum position at the optimum velocity with the optimum timing to produce the desired athletic task.[2] The core is important to provide local strength and balance and to decrease back injury. In addition, since the core is central to almost all kinetic chains of sports activities, control of core strength, balance and motion will maximise all kinetic chains of upper and lower extremity function.

There is no single universally accepted definition of core stability. A general definition of core stability that will be used in this article is the ability to control the position and motion of the trunk over the pelvis and leg to allow optimum production, transfer and control of force and motion to the terminal segment in integrated kinetic chain activities.

3. Anatomy, Physiology and Biomechanics

3.1 Anatomy

The core acts as an anatomical base for motion of the distal segments. This can be considered 'proximal stability for distal mobility' for throwing, kicking or running activities.[2,3] Most of the prime mover muscles for the distal segments (latissimus dorsi, pectoralis major, hamstrings, quadriceps and iliopsoas) attach to the core of the pelvis and spine. Most of the major stabilising muscles for the extremities (upper and lower trapezius, hip rotators and glutei) also attach to the core.

Numerous muscles make up the complex known as core muscles. Some are small, short muscles with small lever arms to span single joints. These are activated in 'length dependent' muscle activation patterns.[4] Others span numerous spinal segments and function as prime mover muscles to integrate several joints and produce force. They are activated in 'force dependent' activation patterns.[4] Coordination of both activation patterns is required in the multi-segmented structure like the spine. The multifidi are an example of short muscles that provide single-joint segmental stabilisation that allow the longer, multi-joint muscles to work more efficiently to control spine motions.[5] This combination of muscle activations helps create the 'neutral zone' control of the spinal segments. In this 'neutral zone' the ligaments see minimal tension.[5-8]

The abdominal muscles consist of the transverse abdominus, the internal and external obliques, and rectus abdominus. Contracting the transverse abdominus increases intra-abdominal pressure and tensions the thoracolumbar fascia. The transverse abdominals have been shown to be critical in stabilisation of the lumbar spine.[9,10] Abdominal muscle contractions help create a rigid cylinder, enhancing stiffness of the lumbar spine.[11] It is important to note that the rectus abdominus and oblique abdominals are activated in direction-specific patterns with respect to limb movements, thus providing postural support before limb movements.[3,12-14] Contractions that increase intra-abdominal pressure occur before initiation of large segment movement of the upper limbs.[15,16] In this manner, the spine (and core of the body) is stabilised before limb movements occur to allow the limbs to have a stable base for motion and muscle activation.[17] Clinically, it has been shown that only a very small increase in activation of the multifidi and abdominal muscles is required to stiffen the spinal segments (5% of maximal voluntary contraction for activities of daily living and 10% of maximal voluntary contraction for rigorous activity).[18]

Core stability requires control of trunk motion in all three planes. In order to provide stability in all planes of motions, muscles may be activated in patterns that are different from their primary functions. For example, the quadratus lumborum (QL) muscle functions mainly as a stabiliser of frontal plane flexion and extension activities. However, the QL is attached from the transverse processes of the spine and the 12th rib to the iliac crests. This orientation allows QL muscle activation that occurs in association with flexion, extension and lateral bending activities to buttress shearing of the spine in the plane of movement, making it more than just a frontal plane stabilising muscle.[19]

The roof of the core muscle structures is the diaphragm. Simultaneous contraction of the diaphragm, the pelvic floor muscles, and the abdominal muscles, is required to increase intra-abdominal pressure, providing a more rigid cylinder for trunk support, decreasing the load on the spine muscles and allowing increased trunk stability.[16,18,20] The diaphragm contributes to intra-abdominal pressure before the initiation of limb movements, thereby assisting spine/trunk stability. This activation occurs independently of the respiratory actions.[21]

At the opposite end of the trunk component of the core muscles are the pelvic floor muscles. Because of the difficulty in directly assessing these muscles, they are also often neglected or ignored with respect to musculoskeletal rehabilitation. Synergistic activation patterns exist involving the transverse abdominus, abdominals, multifidi and pelvic floor muscles that provide a base of support for all the trunk and spinal muscles.[16]

The hips and pelvis and their associated structures are the base of support for the core structures. Critical to functioning of the hip and pelvis are the many major muscle groups in this area. These muscles have large cross-sectional areas and, in addition to their stabilising role, can generate a great deal of force and power for athletic activities. The glutei are stabilisers of the trunk over the planted leg and provide power for forward leg movements.[2,22] The hip/trunk area also contributes around 50% of the kinetic energy and force to the entire throwing motion.[23]

The thoracolumbar fascia is an important structure that connects the lower limbs (via the gluteus maximus) to the upper limbs (via the latissimus dorsi). This allows the core to be included in integrated kinetic chain activities such as throwing.[24] It covers the deep muscles of the back and trunk including the multifidi. The thoracolumbar fascia also has attachments to the internal obliques and transverse abdominus muscles, thus providing three-dimensional support to the lumbar spine and aiding core stability.[24] It helps to form a ‘hoop’ around the abdomen, consisting of the fascia posteriorly, the abdominal fascia anteriorly, and the oblique muscles laterally, which creates a stabilising corset effect.[25]

3.2 Physiology

Muscle activation in kinetic chain function is based on pre-programmed patterns of muscle activation that are task oriented, specific for the athletic activity, and are improved by repetition. These patterns are grouped into the following two classes:

- length-dependent patterns, which confer stability around one joint, are mediated by gamma afferent input and involve reciprocal inhibition of muscle to provide stiffness around a joint;
- force-dependent patterns integrate activation of multiple muscles to move several joints and develop force, and are mediated by Golgi tendon receptors.[4]

Force-dependent patterns of activation are demonstrated in many aspects of core-related activities. Evaluation of muscle activation patterns in association with rapid arm movement shows that the first muscles to be activated are the contralateral gastrocnemius/soleus,[3] and that patterns of activation proceed up to the arm through the trunk.[14,26] Maximum foot velocity in kicking is more highly related to hip flexor muscle activation than knee extension.[3] A study of baseball throwing demonstrated that in all levels of pitching there is a pattern of muscle activation that starts from the contralateral external oblique and proceeds to the arm.[26]

These muscle activation patterns also result in increased levels of muscle activation in the extremities, improving their capability to support or move the extremity. Maximum gastrocnemius plantarflexor power is generated by use of the hip muscles. Twenty-six percent more activation can occur in the ankle as a result of proximal muscle activation.[22] Similarly, a 23–24% increase in maximal rotator cuff activation occurs when the scapula is stabilised by the trapezius and rhomboid muscles, either in asymptomatic or symptomatic individuals.[27,28] In addition, the distal muscle activity can be more directed towards precision and control, rather than power generation, when proximal muscle activation is maximum. This can be seen in the function of the elbow muscles in throwing.[26]

Core muscle activation is used to generate rotational torques around the spine. Most studies of muscle activation demonstrate a differential pattern of intensity and timing of muscle activation, starting

Fig. 1. One-leg stance. No verbal cues are given. Attention should be paid to alterations in posture or arm position.

on the contralateral side, that creates rotation as well as force generation.[16,24,26]

Finally, core muscle activation provides stiffness to the entire central mass, making a rigid cylinder that confers a long lever arm around which rotation can occur and against which muscles can be stabilised as they contract.[16,24,25]

3.3 Biomechanics

Physiological muscle activation results in several biomechanical effects that allow efficient local and distal function. The pre-programmed muscle activations result in anticipatory postural adjustments (APAs), which position the body to withstand the perturbations to balance created by the forces of kicking, throwing, or running.[3,14] The APAs create the proximal stability for distal mobility.

The muscle activations also create the interactive moments that develop and control forces and loads at joints. Interactive moments are moments at joints that are created by motion and position of adjacent segments.[2] They are developed in the central body segments and are key to developing proper force at distal joints and for creating relative bony positions that minimise internal loads at the joint. There are many examples of proximal core activation providing interactive moments that allow efficient distal segment function. They either provide maximal force at the distal end, similar to the cracking of a whip, or they provide precision and stability to the distal end. Maximum force at the foot segment in kicking is developed by the interactive moment resulting from hip flexion.[2] Maximum shoulder internal rotation force to rotate the arm is developed by the interactive moment developed by trunk rotation.[2] Maximum elbow varus torque to protect against elbow valgus strain is produced by the interactive moment resulting from shoulder internal rotation.[2] Maximal fast ball speed is correlated with the interactive moment from the shoulder that stabilises elbow and shoulder distraction[29] and produces elbow angular velocity.[30] Accuracy of ball throwing is related to the interactive moment at the wrist produced by shoulder movement.[30]

As a result of the activations and interactive moments, there is a proximal to distal development of force and motion, according to the ‘summation of speed’ principle[2] that includes core activation. This is not always a purely linear development strictly from one segment to the next. In the tennis serve,

Fig. 2. Trendelenburg position, with the contralateral hip dropped.

Fig. 3. 'Corkscrewing' – using hip rotators to stabilise the trunk over the planted leg in the presence of hip abductor weakness.

elbow maximal velocity is developed before maximal shoulder velocity. However, this general pattern of force development from the ground through the core to the distal segment has been demonstrated in the tennis serve,[23,31] baseball throw[26] and kick.[2]

Force control is also maximised through the core. The trunk is essential in re-acquiring the forward momentum in throwing,[24] and approximately 85% of the muscle activation to slow the forward-moving arm is generated in the periscapular and trunk muscles, rather than the rotator cuff.[32]

4. Advantages of Core Stability in Function

Core stability creates several advantages for integration of proximal and distal segments in generating and controlling forces to maximise athletic function. The larger, bulkier muscles in the central core create a rigid cylinder and a large moment of inertia against body perturbation while still allowing a stable base for distal mobility. In addition, it places most of the 'engine' of force development in the central core, allowing small changes in rotation around the central core to effect large changes in rotation in the distal segments, similar to the cracking of the end of a whip. Because of the need for relatively smaller mass in the peripheral segments, the moment of inertia in these distal areas is less, allowing the summation of higher velocities. Finally, by allowing joint force control to be largely influenced and controlled by pre-programmed muscle activation patterns and interactive moments developed through core activation, instead of being based on local ligament size or feedback-based local muscle activation, the ligaments can be smaller in size, and the smaller local muscles can be activated for precision and control of performance variables.

5. Examples of Failure of Core Stability Associated with Dysfunction

Weak hip muscles and resulting alteration of hip/trunk position are a common finding associated with knee injury. Weak hip abductors and tight hip flexors are seen in association with anterior knee pain and chondromalacia.[33,34] Alterations in hip muscle activity are associated with increased hip varus and hip flexion positioning and increased knee valgus positioning in squatting or landing manoeuvres, all of which increase load on the anterior cruciate ligament. A recent longitudinal study looked at core stability parameters and found that weakness in hip external rotation was correlated with incidence of knee injury.[35] Based on these associations, most rehabilitation and conditioning programmes for the knee now emphasise core stabilisation and hip strengthening.[33,34,36]

Fig. 4. Sagittal plane evaluation. The shoulders should barely touch the wall.

Fig. 5. Frontal plane evaluation.

Alteration of knee flexion has also been associated with increased stresses in the arm. Tennis players who did not have adequate bend in the knees, breaking the kinetic chain and decreasing the contribution by the hip and trunk, had 23–27% increased loads in horizontal adduction and rotation at the shoulder and valgus load at the elbow.[37] A mathematical analysis of the tennis serve showed that a decrease in 20% of the kinetic energy developed by the trunk resulted in a requirement of 34% more arm velocity or 80% more shoulder mass to deliver the same energy to the ball.[23]

Weakness or tightness at the hip can also affect the arm. Decreased hip flexibility in rotation or strength in abduction (positive Trendelenburg) was seen in 49% of athletes with arthroscopically proven posterior-superior labral tears.[38]

6. How is Core Strength Evaluated?

There is no standard way that has been described to measure core strength. Different investigators have used different techniques to try to gauge the relative strengths of specific core muscles via electromyogram data[39] and isometric dynamometer values.[40,41] These data can give an approximate estimate of core strength. Firing of numerous muscles in task-specific patterns to provide core strength makes evaluation of any specific single muscle as a reference point questionable. Any evaluation technique will need to take into consideration that the muscles to be tested should be tested in functional positions when possible. If the muscle is mainly used in a closed chain manner, it should be tested in a closed chain manner. If the muscle is activated in different planes of motion, it should be tested in various planes of motion. If muscles are used primarily in an eccentric manner, they need to be tested in an eccentric manner. Often, to assess all of the different muscles that function together to provide core strength, evaluation of specific motion patterns and quality of movement may be done.[39,40] This method of analysis is harder to quantify, but is more similar to actual three-planar core function. There is no consensus regarding the most reliable or reproducible evaluation system.

One option to assess core strength that incorporates many of these variables is to look at one-leg standing balance ability, a one-leg squat, and a standing, three-plane core strength test. In a standing balance test, the patient is asked to stand on one leg with no other verbal cue (figure 1). Deviations such as a Trendelenburg posture or internally or externally rotating the weightbearing limb indicates inability to control the posture and suggests proximal core weakness (figure 2).

A one-leg squat would be the next progressive evaluation if the standing balance test is done well. Assuming the same starting point as the standing balance test, the patient is asked to do repetitive

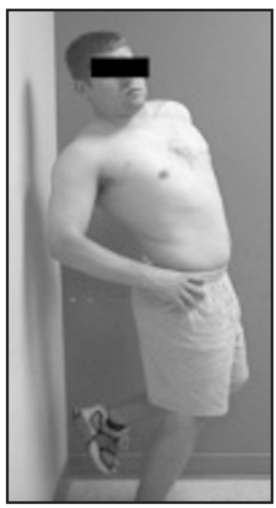

Fig. 6. Transverse plane evaluation.

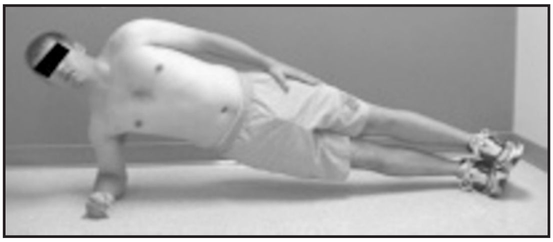

Fig. 7. Horizontal side support exercises.

partial quarter to half squats with no other verbal cues. Similar deviations in the quality of the movement are assessed as in the standing balance test. A Trendelenburg posture, which may not be noted on standing balance, may be brought out with a single-leg squat. The patient may use their arms for balance or may go into an exaggerated flexed or rotated posture ('corkscrewing') in order to put the gluteal or short rotator muscles on greater tension to compensate for other muscular weakness (figure 3).

Three-plane core testing is an attempt to quantify core control in the different planes of spine and core motion. Reliability and validity studies have not been done on specific tests. Clinical experience has demonstrated that this battery of tests does give useful information that allows specific rehabilitation protocols to be instituted for increased core function. Testing is done with the patient standing a given distance (usually 8cm) away from a wall. In sagittal plane testing, they will be facing away from the wall. They are asked to slowly move their body backwards, keeping their feet flat on the floor, to just barely touch their head against the wall (figure 4). Initially, this can be done with both legs on the ground, then progressed to partial weightbearing on each side and ultimately to single-leg standing. Sagittal plane core strength testing creates eccentric activation in the abdominals, the quadriceps and hip flexor muscles, and concentric activation in the hip and spine extensors. Frontal plane testing is done by having the patient standing with one side then the other 8cm away from the wall (figure 5). While standing on the inside leg, they are asked to barely touch their inside shoulder to the wall. This test evaluates eccentric strength of the quadratus lumborum, hip abductors, and some long spinal muscles that are working in a frontal plane. Finally, transverse plane motion is tested by having the patient stand 8cm away from the wall, and progress like the sagittal plane test from bilateral weightbearing to single-leg stance and alternately touch one shoulder then the other just barely against the wall (figure 6). Quality of motion and speed can be assessed. With lesser degrees of core strength, there is a greater breakdown in the ability to maintain single-leg stance and the ability to just barely touch the wall. This test will assess transverse plane motions that incorporate abdominal muscles, hip rotators and spine extensors. Therapy can then be instituted based on the muscles and planes of motion that are found to be deficient.

7. Principles of Core Rehabilitation

Rehabilitation of the core should concentrate on both the intrinsic needs of the core for flexibility, strength, balance and endurance, and on the function of the core in relation to its role in extremity function and dysfunction. A thorough pre-rehabilitation examination including the core and the extremity is required prior to rehabilitation.

The early focus is on the deficiencies discovered during the pre-rehabilitation examination. These usually include both altered patterns of motion of the hip, trunk and shoulder, and actual weakness or inflexibilities of muscles, and may be seen locally or distantly. Specific inflexibilities and weaknesses may be addressed locally by specific exercises, but motion patterns should be addressed on a global level involving the entire kinetic chain motion. Re-

Fig. 8. Isometric trunk rotation.

Fig. 9. Diagonal trunk rotation around a stable base: starting position.

habilitation for extremity injury should start with core emphasis.

In order to create a stable base, the rehabilitation protocols start with the primary stabilising musculature such as the transverse abdominus, multifidus, and the quadratus lumborum. Due to their direct attachment to the spine and pelvis, they are responsible for the most central portion of the core stability. Exercises include the horizontal side support (figure 7) and isometric trunk rotation (figure 8). This stage of rehabilitation is not only to restore core function by itself, but also is the first stage of extremity rehabilitation.

Fig. 10. Diagonal trunk rotation: maximal external rotation.

Progressions for lower extremity rehabilitation include forward and side lunges, integrated trunk rotation/hip rotations, and knee flexion/extensions with trunk rotations.[34,36] The frequency and intensity of each of the exercises will depend on the individual response to the exercises.

Shoulder and upper extremity rehabilitation may begin with a posture of bilateral leg stance, hip extension and trunk extension.[36] Activation patterns may start with ipsilateral muscles and proceed to contralateral activations. Diagonal patterns involving trunk rotation around a stable base imitate the throwing motion (figure 9, figure 10, figure 11). The lower extremity activation drives the scapular and shoulder activation. All upper extremity exercises should end in the same position of trunk/hip extension. One method to assure this posture is to ask the patients to end with ‘the elbows in the back pockets’. Progression for upper extremity rehabilitation include integrated scapular retraction/arm abduction/external rotation and ‘low rows’, integrated trunk extension/scapular retraction/arm extension (figure 12) and hip/trunk rotation with scapular retraction (figure 13).

Core stabilisation should avoid emphasising the use of single planar exercises that isolate specific muscles or specific joints. They may be used at times during the rehabilitation protocol, but emphasis should be on early progression to functional

Fig. 11. Diagonal trunk rotation: cross body motion

positions, motions and muscle activation sequences. In this manner, normal physiological activations are restored, which lead to restoration of normal biomechanical motions. Exercises may be started with the extremity close to the body, decreasing the moment arm, then progressing to more abducted positions, increasing the forces and loads. The goal is to achieve coordination of activation of the segments throughout the entire kinetic chain.

Rehabilitation should be viewed as a ‘flow’ of exercises that build a base of stability and force generation, and then proceed distally to establish control of the forces while allowing maximal mobility of the distal segment.[42] The core is the central part of this flow. It acts as the base of stability and the ‘engine’ of force generation, and also acts as the controller to regulate the forces. Since it is involved in many aspects of all athletic activities, it should be evaluated as part of the workup of any extremity injury, and should be rehabilitated prior to rehabilitation of the injured extremity.

8. Conclusion

Core stability is a pivotal component in normal athletic activities. It is best understood as a highly integrated activation of multiple segments that provides force generation, proximal stability for distal mobility, and generates interactive moments. It is difficult to accurately quantify by isolating individual components, but its function or dysfunction can be approximated by evaluations that reproduce the three-planar motions that are used by the core to accomplish its functions. Better understanding of the complex biomechanics and muscle activations will allow more detailed evaluations and more specific rehabilitation protocols.

Fig. 12. The low row exercise-integrated trunk extension/scapular retraction/arm extension. It may be started isometrically and then progressed to isotonic motion.

Fig. 13. Hip/trunk rotation with scapular retraction. These may be done in various planes of arm elevation.

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