Literature Review:

Core Stabilization From The Inside Out: The Role Of The Diaphragm And Intra-Abdominal Pressure

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Abstract

Objective: The objective of this literature review is to determine the role of the diaphragm and intra-abdominal pressure in the stabilization of the lumbar spine and low back.

The diaphragm plays a crucial role in core stability. The diaphragm is part of the deep stabilizing system of the spine. The diaphragm, along with the other muscles of the deep stabilizing system provides adequate intra-abdominal pressure to create the proper amount of stiffness to stabilize the spine from the anterior. For optimal intra-abdominal pressure there needs to be a balance of co-activation between the deep cervical flexors and spinal extensors in the cervical and thoracic spine, as well as the diaphragm, pelvic floor and the all portions of the abdominal wall including the spinal extensors in the lower thoracic and lumbar spine. The overall conclusion is that the diaphragm is needed to create intra-abdominal pressure, but intra-abdominal pressure is task specific based on the demands of movement and the stabilization required.

Keywords: *Hodges, McGill, Kolar, core stabilization, diaphragm, spinal stabilization, and IAP (intra-abdominal pressure)*.

Background

It has been suggested that the diaphragm plays both a role in respiration and in postural function.[8,9,13,22,23,24,25,36] Most of the discussion surrounding core training or core stabilization have focused on the isolation of muscles, specifically the transversus abdominis (TA).[20] Hodges first linked a decrease in TA activation when a person is experiencing pain, and that in normal, non-painful individuals the TA should activate first before movement of the extremities occurs.[16] Because of this information, the majority of exercise and rehab professionals have focused their efforts in the isolation of activating the TA. Stuart McGill has said that all of the muscles of the "core" are important functionally and that one muscle is not more important than any other.[25,27] Hodges' research did show the importance of the "inner unit" activating first to provide a stable platform to allow for uninhibited extremity motion.[13]

Defining the Core

The article, "Primal Nature of Core Function: In Rehabilitation and Performance Conditioning" by Matt Wallden, focuses on the evolutionary role of the core. Wallden describes the core as the foundation in which all other function has grown from.[37] Because the core is considered the foundation of movement, the greater the desired performance the more solid the platform must be.[37] The human core is similar to those found in primates, reptiles and even fish.[37] From an evolutionary perspective the "core" and the digestives systems have been linked.[37] Embryologically the core musculature is developed from the same mesoderm tissue as the digestive tract.[37] The article offers a suggestion for a definition of the core musculature as the transversus abdominis, pelvic floor, diaphragm and multifidus. This has been described as the inner unit, which must work in concert with the outer musculature of the abdominal wall.[37] For optimal core function, breathing must be normalized before addressing the stabilizing role or strength of the core.[37]

The article, "Diaphragmatic Breathing: the Foundation of Core Stability" by Nicole Nelson outlines that diaphragmatic breathing is the most fundamental function of the core. Nelson suggests that optimization of breathing and diaphragmatic control should precede any other activity addressing spinal stability.[31] The diaphragm is considered the roof of the inner unit, with the pelvic floor being the base, the mutifidus makes up the posterior aspect, and the transversus abdominis comprise the walls of the abdominal cylinder.[31,32] These deep muscles, which attach to the spine, are thought to directly influence the stability of the spine. The mechanism that best describes the action in which this stability takes place is by intra-abdominal pressure. The diaphragm creates a plunger-like action as it descends combined with eccentric contraction of the pelvic floor, transversus abdominis, and multifidus to create negative pressure in the plural cavity, allowing for an increase in intra-abdominal pressure in the abdominal cavity.[31] Karel Lewit states, "That if healthy breathing patterns are not in place, than no other movement pattern can be."[26] Lewit also states, "Breathing may well be considered a competency in which further movement development is based upon, and developing efficient breathing patterns should be prioritized."[26] The conclusion of the article is proper breathing habits can affect the stability of the spine and allow the diaphragm to function with duel roles of postural stabilization and respiration.[31]

The article, "The Role of Core Stability in Athletic Function" by Ben Kibler et al aims to define the core and outline its importance during athletic activities. Kibler et al define the musculoskeletal core as the spine, hips and pelvis, proximal lower limb and abdominal structures.[21] These structures are responsible for the maintenance of spinal stability and transferring energy to the distal extremities.[21] This concept is important in providing proximal stability for distal mobility.[21] There is not a unified definition of core stability but Kibler et al define it as "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".[21] Kibler et al address the role of the diaphragm as the roof of the core and its importance in creating intra-abdominal pressure. An increase in intra-abdominal pressure decreases the load on the surrounding spinal musculature, optimizing spinal stability.[21] The diaphragm is also important in creating increased intra-abdominal pressure before the initiation of movement of the extremities assisting in truck stability.[21] The conclusion of the article is the trunk/core must provide a foundation for force generation throughout the entire body and intra-abdominal pressure is key in providing that foundation.[21,32]

Introduction

The musculotendinous dome of the diaphragm creates a partition separating the thoracic and abdominal cavities.[3] The diaphragm is the most important muscle responsible for respiration.[25] The diaphragm is the primary muscle involved during quiet inspiration.[25] The diaphragm also plays an important role in the co-activation pattern during upright posture.[25] As we mature the diaphragm settles into a horizontal position, which takes place about the fourth month.[7,25] The diaphragm makes up the ceiling of the abdominal canister with the pelvic floor being the floor of the canister, the transversus abdominis being the walls and the multifidus being the posterior boundary.[25,32] As the diaphragm contracts, the dome shape flattens pressurizing the abdominal canister.[25] The co-activation of the previous muscles mentioned, creates intra-abdominal pressure.[7,25,32] Intra-abdominal pressure is the key stabilizing component of the lumbar spine from the anterior.[7,25] Thus the diaphragm is involved with both respiration and spinal stabilization.[25] Intra-abdominal pressure allows for sagittal stabilization of the spine.[7,25] Sagittal stabilization should occur before frontal and transversus stabilization take place.[7,25]

During the course of normal development, co-activity between the agonist and antagonist become balanced, which enables upright posture.[7,25] The deep stabilizing system is important to maintain upright posture of the spinal column.[7,25] The deep stabilizing system is comprised of the multifidus, transversus abdominis, diaphragm and pelvic floor.[7,25] The multifidus, transversus abdominis, diaphragm and pelvic floor provide support for the abdominal wall.[25] These muscles also play an important role in creating intra-abdominal pressure to stabilize the spine from the anterior.[7,25] In humans, the diaphragm plays a duel role in both respiration and postural function, specifically spinal stabilization.[8,9,13,22,23,24,25,36] During normal contraction of the diaphragm the central tendon descends, pressurizing the abdominal cavity.[3,25] This pressurization is accompanied by eccentric contraction of the deep abdominal muscles.[25] This mechanism is important to allow the thorax to be fixed to the pelvis, which facilitates increase lumbar stability.[25]

In contrast, if the diaphragm’s position is altered (no longer horizontal) and becomes more oblique, similar to Janda’s lower cross syndrome (anterior pelvic tilt) or as seen in faulty breathing patterns when the accessory muscles of respiration become dominant and the thorax becomes fixated in a rostral or inspiratory position, while the lumbar spine demonstrates loss of sagittal stabilization.[4,19,25] With decreased sagittal stabilization and the ribcage is no longer fixated to the pelvis, lumbar stability is compromised.[4,25] It is important for the deep local muscles to contribute to the support of the pelvis.[19] Lumbopelvic stability is reliant on the myofascial connections of these deep local muscles to provide the structural support for the lower torso and legs.[19] These deep stabilizing muscles act collectively as internal agonists to balance the activity of the global stabilizing muscles.[19] "Balanced co-activation from the lumbopelvic unit provides internal stability to the pelvis as it swings and swivels on the femoral heads which is necessary in weight shift, load transfer and controlling equilibrium," Josephine Key describes this as "core control".[19]

All muscles of respiration have attachments to the ribs.[3,39] In addition to aiding respiration; all these muscles are involved to some extent with stabilizing the thoracic cage during trunk movements.[4] The diaphragm is the primary muscle of respiration.[3] The shape of the diaphragm is similar to that of a parachute, which is comprised of a musculoteninous sheet that is convex superiorly. The diaphragm separates the thoracic cavity from the abdominal cavity.[3] The origin of the muscular fibers that make up the diaphragm begins at the central tendon.[3] From the central tendon the fibers attach to the xiphoid, the deep surface of the lower six ribs and their costal cartilage and in addition the diaphragm interdigitates with the transversus abdominis, as well as attaching to the lateral and medial lumbo-costal arches and the first three lumbar vertebrae.[3,4]

The diaphragm is asymmetrical; therefore our stabilization mechanism will be asymmetrical.[4,39] The left side will always be weaker because we have a smaller diaphragm on that side.[4,39] The zone of apposition is the vertical distance from the apex of the diaphragm to the bottom of the rib cage, roughly T8 vertebra.[4,39] The more dome shaped the zone of apposition the greater the mechanical advantage the diaphragm has for lumbo-pelvic and hip stabilization.[4,39] Because of the lack of stability and decreased size of the diaphragm on the left side, the structures on the left side, are prone to tightness, which is similar to the findings that Janda describes in his faulty movement patterns.[17,18,19,39]

Methods

The information used to write this literature review was gathered from Internet databases obtained during the time span of July 2013 to August 2013. The Internet databases were accessed through the learning resource center at Logan College of Chiropractic and include the following: PubMed, Google Scholar, and OvidSP. Keywords include: Hodges, McGill, Kolar, core stabilization, diaphragm, spinal stabilization, and IAP (intra-abdominal pressure). Only articles that were available as free full text were used. No limits were placed on the publication date of the studies within this paper. No limitations of the type of study were done either.

Postural Role of the Diaphragm

The postural role of the diaphragm is closely linked to the role the diaphragm plays in creating intra-abdominal pressure.[22,23,24] While the diaphragm has always been considered a principle muscle for breathing, its role in postural function has been studied less.[9] Gandevia et al concluded through EMG research that during rapid movements of the extremities the diaphragm is activated approximately 20 msec. before the start of prime mover activity of the extremities.[8] This means the diaphragm is activated in a feed-forward manner in anticipation of motion occurring in the distal joints of the extremities, specifically the shoulder or elbow.[7,8] The diaphragm is the main component of the deep stabilizing muscles of the core and contributes to the functional inner unit for dynamic spinal stabilization. "The diaphragm precedes any movement of the body by lowering and subsequently establishing abdominal pressure, which helps stabilize the lumbar spine"-Pavel Vostatek.[36] Vostatek et al also concluded that for proper stabilization to occur the ribs must be in the ideal expiratory position.[36] The expiratory position of the ribs allows the diaphragm and pelvic floor to be parallel to each other providing the ideal intra-abdominal pressure to stabilize the lumbar spine.[36] In the article, "Spinal Stiffness Changes Throughout the Respiratory Cycle," the results of the study were spinal stiffness increased with both inspiratory and expiratory efforts, but expiratory efforts contributed the most to spinal stiffness.[33] Shirley et al summarized their findings that the expiratory position provided the greatest amount of spinal stiffness.[33] In addition to identifying the expiratory position of the diaphragm creating spinal stiffness, Shirley et al also found that the attachment of the diaphragm to the lumbar spine contributed to different levels of stiffness.[33] The upper lumbar segments L1 and L2 had higher levels of stiffness due to the crural attachments of the diaphragm to the lumbar spine than the lower segments where there is no crural attachment.[33] A conclusion of the study performed by Hodges et al in 1997 is that the contraction of the diaphragm contributes to increased intra-abdominal pressure, prior to the initiation of movements of large segments of the upper limb.[9] The preparatory contraction of the diaphragm is also associated with the simultaneous activity of the transversus abdominis.[9] According to Hodges et al 2000, "Of the abdominal muscles, only the transversus abdominis activity is modulated in conjunction with both respiratory and postural demands during limb movement."[13] In addition to being the only abdominal muscle to respond to both respiratory and postural functions the transversus abdominis is also, "the first abdominal muscle to be recruited when expiration is increased with chemical or elastic loading."[13] This is of no surprise because Bruno Bordoni et al as well as Bartelink's research has linked the transversus abdominis and the diaphragm embryologically.[2,3] Hodges et al 1997 research also concluded "diaphragmatic contraction could increase stability of the trunk by minimizing displacement of the abdominal contents into the thorax, thus maintaining the hoop-like geometry of the abdominal muscles."[9] According to Hodges' work from 1997 "the diaphragm is concluded to be pre-programed by the CNS and may be initiated as part of the motor command for movement."[9]

Kolar's article, "Analysis of Diaphragm Movement During Tidal breathing and During its Activation While Breath Holding using MRI Synchronized with Spirometry" examined the voluntary activation of the diaphragm using MRI. Even though the diaphragm is generally thought of as the primary muscle used during breathing, it can voluntarily be used for postural stability.[22] The authors of the article focused on the voluntary contraction of the diaphragm and how it helps contribute to an increase in intra-abdominal pressure and spinal stabilization. Kolar's previous research confirmed that spinal stabilization increases with increased transdiaphragmatic pressure, which allows for optimal muscle function of the attached extremities.[22] The article also utilized Hodges previous work that looked at the stabilizing function of the diaphragm on the lumbar spine before the initiation of movement of the extremities occurs. Kolar's findings, which the CNS anticipates movement in the extremities and must stabilize the spine, pelvis and torso in a feed forward manner as a point of support to allow optimal expression of movement is consistent with Hodges' work.[22] Another finding of the research in the article was the spinal extensors are recruited when the diaphragm does not provide enough support for the lumbar spine.[22] The conclusion of Kolar's article was the diaphragm is activated independently of respiration.[22] Kolar used MRI to confirm during breath holding the diaphragm still has the ability to descend further by active contraction, beyond the change in pressure in the abdominal cavity.[22]

The article, "Stabilizing Function of the Diaphragm: Dynamic MRI and Synchronized Spirometric Assessment" looked at the position of the diaphragm using dynamic MRI to assess the excursion of the diaphragm and how it relates to spinal stabilization. The results of the study demonstrated greater diaphragmatic excursions occurred when the upper or lower extremities were activated compared to static posture.[24] Another finding was the diaphragm does not function as one unit.[24] The diaphragm was shown to activate different portions based on postural demands.[24] The article also discusses the role respiration has on postural control and how postural demands can influence the diaphragm. When the extremities are activated the diaphragm's position on both inspiration and expiration is in a lower position, which indicates greater postural demand on the diaphragm.[22] With the lower extremities active the expiratory position of the diaphragm is lower than the expiratory position of the diaphragm during normal tidal breathing.[22] This indicates that the diaphragm is under higher tonic state activity, confirming the diaphragm is involved with spinal stabilization during postural movements.[22]

The article, "Postural Function of the Diaphragm in Persons with and without Chronic Low Back Pain" by Kolar et al examined the different stabilizing strategies people utilize with and without back pain. Their findings support the idea that the CNS alters core stability in the presence of pain.[23] The study looked at tidal breathing and the difference in the diaphragms position in people with and without back pain. During normal tidal breathing, no differences were shown in the diaphragms recruitment, but during postural tasks with arm or leg movement, altered diaphragm recruitment was demonstrated.[23] There was reduced activation in the anterior and middle portions of the diaphragm, while the posterior aspect activated in a similar manner in both groups.[23] In the group of people with back pain the slope of their diaphragm was steeper than those without back pain, meaning that the diaphragm was in an oblique position to the pelvic floor.[23] This position of the diaphragm limits the amount of intra-abdominal pressure that can be produced, thus decreasing the stabilizing aspect of the diaphragm.[23] Another consequence of the diaphragm being out of the optimal position for respiration and stabilization is the accessory muscles of respiration must be involved during quiet breathing, leading to further dysfunction.[23] The article brings up the question, does low back pain cause poor activation of the diaphragm or does poor activation of the diaphragm cause low back pain. The question was asked as part of future research on the topic. The results of the pulmonary function tests were somewhat surprising; they were in the normal range for both groups. The conclusion from this was compensation from the accessory muscles of respiration keeps the pulmonary function values with in the normal limits.[23] The study looked into other compensations, such as in normal subjects the diaphragm is able to perform both respiration and stabilization. The stabilization is achieved by increasing intra-abdominal pressure. If the diaphragm is not able to perform its stabilizing role, prime movers are recruited to become stabilizers.[23] The overall conclusion to the article was individuals with low back pain use different strategies of diaphragmatic activation, which compromise spinal stability.[23]

Intra-Abdominal Pressure and Spinal Unloading and Spinal Stability

Research dating back to the 1920's has looked at the mechanism of unloading the spine through the generation of intra-abdominal pressure (IAP).[30] The proposed mechanism was that IAP generates an extensor moment that supports the spine.[30] The conclusion of Mokhtarzadeh et al research was fiber orientation of the muscles plays a role in creating IAP.[30] Their conclusion was that the muscle fibers needed to run in a transverse or horizontal pattern to produce the needed IAP to unload the spine.[30] They found that muscle fibers with an oblique orientation up to sixty degrees could contribute to spinal unloading.[30] Mokhtarzadeh et al focused their research on the transversus abdominis (TA) and the internal abdominal oblique (IAO) as the main muscles based on their fiber orientation that contributes to the production of IAP.[30] Their research does not mention the importance of the diaphragm in generating IAP. Another aspect of Mokhtarzadeh's research looked into the dual role of the TA and the IAO have on spinal mechanics. Because of the fiber orientation they suggest that the muscles not only unload the spine but also stabilize the spine without increasing a compressive penalty to the spine.[30] The article also mentions Cholewicki's research and that he concluded that IAP plays a greater role in stabilizing the spine than unloading the spine. The final conclusion of the article "The Effects of IAP an the Stability and Unloading of the Spine" by Mokhtarzadeh et al was the support of rehabilitation applications to train the trunk muscles for strength, endurance and coordination for more effective performance during functional tasks.[30]

It is suggested in Bartelink's article, "The Role of Abdominal Pressure in Relieving the Pressure on the Lumbar Intervertebral Discs" that there is a feed-forward reflex that takes place before movement of the limbs to stabilize the trunk.[2,7] This reflex is an inborn mechanism to provide additional support for the spine.[2,7] The reflex stimulates the diaphragm to contract to pressurize the abdominal cavity. The increase in pressure eccentrically loads the transversus abdominis, multifidus and pelvic floor.[2] This co-contraction creates a muscular framework for increased lumbar support.[2] Bartelink's article also mentions the importance of the lungs being outside of the abdominal cavity. By having two separate cavities, the plural cavity and the abdominal cavity separated by the diaphragm, allows for respiration to take place even when the abdomen is being used for additional lumbar support via IAP.[2] Bartelink also came to the conclusion that the amount of IAP generated was task specific.[2] Meaning the greater the demand of the activity, the greater amount of IAP that needs to be generated to provide spinal support.[2] The overall conclusion of Bartelink's paper was the reflex contraction of the abdominal wall is a protective mechanism for the spine, but in addition the mechanism can be activated voluntarily to reduce the compressive load to the intervertebral discs.[2]

It has been debated for years that an increase in intra-abdominal pressure can unload the spine.[1] While the exact mechanism and the amount in which the spine can be unloaded remain controversial. In the paper, "Role of Intra-Abdominal Pressure in the Unloading and Stabilization of the Human Spine During Static Lifting Tasks" by Arjmand et al has tried to use a mathematical model to predict the values of the amount the spine can be unloaded. Arjmand et al state that the spine can become unloaded in standing posture only if the amount of abdominal co-contraction is minimal.[1] As the amount of abdominal co-contraction increases the amount of spinal unloading decreases to negligible amounts.[1] When lifting in a flexed posture, spinal unloading from IAP only decreased in the presence of large abdominal co-contractions.[1] The stabilizing function with increased IAP during standing improved with abdominal co-contraction, while in a flexed posture the stabilizing function diminished with increased coactivity of the surrounding abdominal muscles.[1] Overall the conclusion of the article was stability and unloading of the spine with IAP is task specific.[1] This article makes no reference to the diaphragms ability to create IAP or how the diaphragm contributes to IAP or spinal stability.

In the article, "Intra-Abdominal Pressure and Abdominal Wall Muscular Function: Spinal Unloading Mechanism" by Stokes et al conclude in their research that with higher the intra-abdominal pressure there is a decrease in the magnitude of spinal compression.[34] The mechanism of spinal unloading that Stokes suggests is due to the lateral abdominal wall contracting to produce IAP against the diaphragm and pelvic floor, thus unloading the spine with an extensor moment.[34] Stokes does state that the diaphragm must be activated to support the pressure differential between the abdomen and the thorax, but did not account for it in his model.[34] Stokes suggests that increased activity in the lateral abdominal wall, specifically the transversus abdominis and the internal abdominal oblique can overcome the flexion moment produced by the anterior abdominal muscles.[34] The results of Stokes et al research suggest that there was less predicted posterior muscle activity with increased IAP.[34] Unlike some of the previous research mentioned, Stokes does not account for the contribution of the diaphragm to IAP, and his model considered the diaphragm a rigid structure for the containment of the increased IAP created by the lateral abdominal wall. According to the results of Stokes et al research, the model that they created demonstrated a reduction in spinal compression force between 18-31%, which was associated with an increase in intra-abdominal pressure of either 5 or 10 kPa.[34]

Intra-Abdominal Pressure and Spinal Stiffness

In the article, "Intervertebral Stiffness of the Spine is increased by Evoked Contraction of the Transversus Abdominis and the Diaphragm: In Vivo Procine Studies" the authors examined the effect of the transversus abdominis (TA) and diaphragm contraction on intra-abdominal pressure and lumbar spine stability. In this study the activity of the TA and diaphragm were looked at independently of the other surrounding trunk muscles. It has been established that these muscles are important in controlling intervertebral stiffness, but this study looked at whether the motion was controlled by the increase in of intra-abdominal pressure or the crural attachments to the lumbar spine. In this study the phrenic nerve was stimulated to activate the diaphragm and transversus abdominis only, to determine their contribution their contribution to spinal stability without the influence of the additional muscles of the torso.[15] The results of this study were spinal motion was reduced when the diaphragm or transversus abdominis was stimulated.[15] This study also looked at the importance of the crural attachments of the diaphragm and transversus abdominis to the lumbar spine. When the researchers cut the crural attachments there was an increase in intra-abdominal pressure to counteract the potential loss of lumbar stability.[15] Overall the conclusion of the article suggests increased intra-abdominal pressure and the contraction of the diaphragm and transversus abdominis provide adequate spinal stiffness to control spinal motion.[15]

In the article, “Spinal Stiffness Changes Throughout the Respiratory Cycle” by Shirley et al examined how spinal stiffness changes throughout the respiratory cycle. The results of the study were during normal tidal breathing spinal stiffness did not change, but spinal stiffness was increased when lung volume increased beyond functional reserve capacity.[33] There was a positive association between increased levels of torso muscle EMG activity and increased intra-abdominal pressure with increased spinal stiffness.[33] The conclusion of the article suggests that increased activity of the diaphragm creates elevated levels of intra-abdominal pressure, which contributes to spinal stiffness.[33]

Hodges work in 2005 concludes that direct stimulation of the diaphragm without the influence of the surrounding abdominal muscles contributes to an increase in intra-abdominal pressure.[11] While it has been shown the abdominal and extensor muscle groups contribute to spinal stability, this research indicates that intra-abdominal pressure is an additional mechanism that contributes to spinal stability.[11]

In the article, “Observations on Intra-Abdominal Pressure and Patterns of Intra-Muscular in Man” looked at the relationship of increased intra-abdominal pressure and the muscles of the abdominal wall that contribute to the elevation of intra-abdominal pressure. The results of the article suggests intra-abdominal pressure created voluntarily as during a valsalva maneuver is result of the entire abdominal wall contracting, not an individual muscle.[6] The article concludes that the creation of intra-abdominal pressure is task specific based on the demands of movement and the stabilization required.[6] The article does not look at the diaphragm's contribution to creating intra-abdominal pressure. The article only looked at how the abdominal wall helps produce intra-abdominal pressure.

Another article titled, "Links Between the Mechanics of Ventilation and Spine Stability" by Simon Wang and Stuart McGill examine how ventilation demands change spinal stability. The article states that the same muscles used for respiratory ventilation are the same muscle used to increase spinal stability.[38] The article used the previous work or McGill and Cholewicki, stating that spinal stability is related to the muscles of the trunk.[38] Another study used in the article was by Shirley et al from 2003, which stated that torso stiffness was related to increased abdominal wall muscle activation and increased intra-abdominal pressure.[33] The research of Wang and McGill agreed with the work of Shirley et al. The results of Wang and McGill's study were with increased lung volumes, torso stiffness increased and the greatest spinal stiffness was at higher lung volumes above the volume of normal tidal breathing.[38] Although the data suggest that increased spinal stiffness occurs with inspiration the article states it is difficult to provide recommendations on breathing in terms of spinal stability.[38] The article goes on to use Shirley's work, stating that inspiration would recruit the diaphragm to help with stiffening the spine.[33] The article also uses Cholewicki's research again, stating with heavy loads the breath must be held to increased intra-abdominal pressure and spinal stiffness.[5] The conclusion of the article was increased lung volume with inspiration correlates with increased spinal stiffness, explaining why weight lifters and sprinters increase lung volume and hold their breath to stabilize their spine during competitive events.[38] The opposite was also found to be true, with decreased lung volume, there was a loss of torso muscular activity and decreased spine stability.[38]

Discussion

The concept of core stabilization practically started with abdominal hollowing and the work of Paul Hodges et al on the transversus abdominis and how it activates before movement of the extremities.[9] His work also looked at how in individuals with back pain the transversus abdominis has a delayed onset of activation.[16] After the publishing of this work, practitioners started incorporating the abdominal hollow to activate the deep core. Despite the research of Hodges, it has been shown recently that abdominal bracing is more effective than abdominal hollowing to activate the global stabilizing muscles of the trunk.[27,35]

Another theory was instability training. The idea behind incorporating instability training was the body had to overcome the instability and the abdominals and deep back muscle must work harder and thereby the core would get stronger.[28] There was a study that looked at rectus abdominis and erector spinae, which showed increased activity when performing exercises on a Swiss-ball.[28] This also sparked clinicians to add an element of instability to common exercises in hopes of increasing the activation of the core musculature.

Although the idea of core stability has been around for years, there is not a proper definition of what core stability truly is. There have several individuals try to come up with their own definition or a list of muscles that are the most important when it comes to core stability. There has also been an emphasis on an anatomical description of core stability instead of it being a function. Most of the current theories of core stability have dealt with the core from the outside in, with the emphasis on tightening certain muscles to create spinal stability. McGill's idea of bracing the core before performing exercises or activities is still only tightening the outer muscles of the abdominal wall.[27,35]

There are two studies conducted by Pavel Kolar that looked at diaphragm function with the help of MRI. The first study concluded that the diaphragm has a postural function and that individuals can activate this function voluntarily.[22] The other finding of this first study was the position of the diaphragm was in a lower position when the extremities are active, indicating that the diaphragm is active during postural tasks.[22] In the second study, Kolar was able to demonstrate the diaphragm has dual functions, a respiratory role and postural role.[24] The conclusion of the second study was the diaphragm is able to maintain its respiratory function while the diaphragm is in a lowered position to create adequate intra-abdominal pressure during a postural task.[24]

Kolar's work is in agreement with the work of Paul Hodges from 1997. At that time Hodges determined that the diaphragm had dual functions, both postural and breathing.[9] Hodges concluded that the diaphragm, pelvic floor, multifidus and transversus abdominis are all active prior to the movement of the extremities.[9] Hodges et al also measured the movement of the lumbar spine with increased intra-abdominal pressure from direct stimulation of the phrenic nerve.[10] Direct stimulation of the phrenic nerve was used to isolate the diaphragms contribution of intra-abdominal pressure from the rest of the abdominal wall musculature.[10] The conclusion of their research was when intra-abdominal pressure was increased an extensor moment was produced.[10] Hodges and Gandevia concluded that rapid movement of the upper arms activated the diaphragms postural function unrelated to breathing.[12]

In normal upright posture, spinal stability should be reflex driven.[17] The normal postural reflex mechanism allows for small shifts and adaptive movements that become learned automatic responses.[17] This automatic sensorimotor control becomes a prerequisite and forms the foundation, which all movements occur.[17] According to Josephine Key, "Ideally, we should demonstrate a 'central intelligence' in the torso- balancing upright control, movement and breathing in an efficient manner."[17] The deep local stabilizing muscles, including the diaphragm, help contribute to the postural reflex.[17] These muscles provide the inner support and control of the axial skeleton.[17] The diaphragm plays an important role in providing the necessary intra-abdominal pressure to pressurize the abdominal canister to give the spine anterior support.[7,17] This concept is supported by Hodges work that early activation of theses muscles occurs prior to movement; this allows the torso to be stable but adjustable to allow for an optimal base of support for the larger prime movers to act on.[10]

Josephine Key emphasizes Janda's contribution to describing faulty movement patterns. Her study of Janda's work has concluded that faulty movement patterns are result of overactive global muscle activity and inhibited local stabilizers.[18] In all of the faulty postures, the diaphragm is put into a compromised position for less than optimal respiration and stabilization.[18] The diaphragm should function as a piston to create intra-abdominal pressure.[18]

With muscle imbalances and faulty postures the diaphragm position becomes more oblique to the pelvic floor, thus increasing the need to utilize the accessory muscles of respiration.[18]

Conclusion

The concept of core stability started with Australian research of motor control of the postural muscles.[20] Part of this research studied the role of the muscles that are responsible for generating intra-abdominal pressure.[20] The researched looked at the feed-forward or anticipatory mechanism of intra-abdominal pressure as an important antigravity/postural control function in spinal stabilization.[7,20] It was found that the muscles of the inner unit or the deep spinal stabilizers (diaphragm, pelvic floor, multifidus and transversus abdominis) all co-activate in advance of limb movement.[20] Breathing and postural control are linked and are important in generating the proper amount of intra-abdominal pressure.[20] "The diaphragm plays a crucial role in generating these internal pressure change mechanisms. Intra-abdominal pressure in variable measure is behind them all."[20] The amount of intra-abdominal pressure needed to stabilize the spine is proportional to the demands of the movement or activity.[20] "In the developmental sequence, breathing becomes integrated into our evolving patterns of posturo-movement control. Breathing and postural control are inextricably linked- each supports the other."[20] Typically optimal posture and optimal breathing are synonymous, but in dysfunctional posture, breathing patterns are usually compromised.[20] An important concept of intra-abdominal pressure is the fact that it does not create rigid stability.[20] "Instead, it affords a buoyancy and resilience to axial antigravity control. This promotes adaptable, flexible intersegmental control and three-dimensional postural weight shifts and adjustments throughout the whole spine."[20] Overall balanced muscular activity of the abdominal wall provides the ideal thoraco-pelvic alignment for optimum generation of intra-abdominal pressure and postural control.[20]

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