Chapter 2.1

Dynamic Neuromuscular Stabilization: developmental kinesiology: breathing stereotypes and postural-locomotion function

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CHAPTER CONTENTS

Breathing, like postural function, is an essential function of any living organism. However, ideal functional models or norms for either breathing or human postural patterns are not universally defined. Various authors and scientific articles define such basic 'functional norms' quite differently. Although, as Dr. Lewit states, function is as real as structure; physiology is as relevant as anatomy; function forms structure and structure serves function, and ideal functional stereotypes are to this day not unequivocally defined as anatomical norms tend to be. Specifically, from a clinical perspective, there is no consensus regarding whether a given individual's breathing pattern or posture can be assessed as ideal or incorrect. Two experienced clinicians will assess the same patient quite differently. They will select different additional examinations and they will differ in opinions regarding the primary etiology of symptoms and may, quite noticeably, differ in the selected treatment strategy. It can be quite difficult for an independent and knowledgeable observer to decide whose approach is correct.

Dynamic Neuromuscular Stabilization (DNS) is an approach based on developmental kinesiology and defines functional norms from a developmental perspective. Compared to many mammals, humans at birth are extremely anatomically and functionally immature – this includes the central nervous system (CNS) (Vojta 2004, Vojta & Schweizer 2009). Structural development is incomplete; e.g. a newborn does not present with definite spinal curvatures (Kapandji 1992, Lord et al. 1995), they are barrel-chested (Openshaw et al. 1984) and their foot structure is not fully formed (Volpon 1994). A newborn has an immature CNS and as a consequence immature muscle function, and postural-locomotor, breathing and sphincter functions.

Following birth, the trajectory of intrauterine development more or less continues and CNS maturation is a significant aspect of this development, including myelination, synaptogenesis, apoptosis and neurotransmitter activation. In conjunction with a certain level of CNS immaturity, a healthy infant presents with typical postural-locomotor patterns that are characteristic for a given age

(Hermsen-van Wanrooy 2006, Vojta 2004, Vojta & Schweizer 2009). Therefore, it can be said that movement patterns are genetically determined and specific only to humans. This includes the breathing pattern and functional norms of a human that depend on CNS control and on the quality of anatomical structures whose corresponding function they serve.

Functional norms are encoded within the CNS in the form of programmes and they are altered in different ways in pathological states.

DIAPHRAGM FUNCTION FROM A DEVELOPMENTAL PERSPECTIVE

In a human embryo, the origin of the diaphragm is concentrated in the cervical region, possibly as an extension of the rectus abdominis muscle (or the 'cervical portion' of the rectus cervicis muscle). During development, the diaphragm descends caudally and tilts forward. This development continues after birth and the diaphragm attains its definite position in an almost transverse plane between 4–6 months.

The muscular portion of the diaphragm has two main parts with different embryonic origins: costal and crural (Pickering & Jones 2002). They are formed by different types of fibres and have specific influence on the ribcage and purposeful movement; e.g. during vomiting or belching, the costal fibres are active while the crural fibres around the esophagus are inactive (Abe et al.1993). The dorsal mesesophagus and mesogastrium partially contribute to the development of the crural portion, which plays an important role in the sphincter function of the diaphragm (Langman 1981).

During ontogenetic development, the diaphragm initially participates in respiration (Murphy & Woodrum 1998). With completion of the neonatal developmental stage (the first 28 days of life), the diaphragm begins to contribute in both postural and sphincter functions. The non-respiratory functions of the diaphragm emerge as the postural anti-gravity role develops – the infant begins to prop up onto forearms and lifts the head when prone or in supine lifts the lower extremities (LE) above the mat (Hermsen-van Wanrooy 2006, Vojta 2004, Vojta & Schweizer 2009). This combined postural-respiratory function of the diaphragm is an important prerequisite for trunk stabilization followed by locomotor movement of the upper and lower extremities (Hemborg et al. 1985, Hodges & Gandevia 2000a, Hodges & Gandevia 2000b, Kolar et al. 2010).

The diaphragm of a healthy newborn is flat and positioned cranially (Devlieger et al 1991); the thorax short and cone-shaped (Openshaw et al. 1984). The posterior rib angles are ventral to the spinous processes, and neither the spinous nor the transverse processes have a definitive shape. The transverse processes exhibit a progressive posterior and inferior angulation with age and move down the thoracic spine. The facet joints angulate accordingly (Lord et al. 1995). The distances between the jugular fossa and the xyphoid process and between the xyphoid process and the pubic symphysis differ from an adult. The newborn has a 'short' thorax and a 'long' stomach. The thoracic cavity of the newborn is limited by the thymus and diaphragm excursion is limited by the large liver. Only breathing movements are realized by the activity of the diaphragm; it does not yet participate in postural and sphincter functions (Murphy & Woodrum 1998).

With CNS maturation, muscle co-activation develops when the neonatal stage is completed. Simultaneous and balanced activity of the agonists and the antagonists allows for active body posture within the gravitational field. An infant no longer only passively lies on the mat, but begins to lift the head and the extremities above the mat and stabilization, support and equilibrium functions develop (Hermsen-van Wanrooy 2006, Vojta 2004, Vojta & Schweizer 2009).

Simultaneous and symmetrical co-activation of the diaphragm, abdominal, back and pelvic muscles allows for the interconnection between breathing pattern and stabilization function (Hodges et al. 2007, Hodges & Gandevia 2000a, Kolar et al. 2009). This combined muscle function is relatively challenging and is only possible in a healthy CNS, which allows for perfect motor control (Assaiante et al. 2005, Hodges & Gandevia 2000a). A disturbance in CNS control causes not only a deficit in movement patterns, including the breathing pattern, but also structural deformities (Koman et al. 2004). A child with a developmental CNS dysfunction will never demonstrate an ideal skeletal anatomy.

Central motor programmes coordinate muscles that significantly influence growth plates. If muscle function is balanced and ensures a symmetrical pull in the area of the growth plates, it is very likely that the anatomical development will be correct. Muscle imbalance during ontogenesis results in less than ideal skeletal development. In extreme cases (e.g. cerebral palsy), various deformities can be observed in extremity joints (e.g. coxa valga antetorta neurogenes) and the thorax (Koman et al. 2004). Respiratory function will then be modified not only as a result of less than ideal CNS control but also as a result of an abnormal shape and position of the spine, ribs, clavicles and other structures.

In a physiologically normal situation, at 3 months the stabilization quality of muscle synergies increases, the cervical and thoracic spine straightens and development of lower costal breathing begins. At 4½ months, when the differentiation of extremity function occurs in the form of support and stepping (grasping) movements, the differentiation function of the muscles of the trunk and the abdominal cavity continues. A child begins to use one upper extremity (UE) and one lower extremity for support and the opposite UE and LE for stepping. This differentiated function allows for active grasp and later for crawling and ambulation (Hermsen-van Wanrooy 2006, Vojta 2004).

Trunk muscles must serve as a support base for extremity function within the framework of such movement patterns. Through intra-abdominal pressure regulation, they contribute to spinal stabilization and, at the same time, ensure respiratory function and influence other visceral functions (food intake, peristalsis, defecation, vomiting, etc.). At 4½ months, the infant also begins to coordinate breathing with vocalization.

In the 6-month-old, costal breathing is fully established. While the combined activity of the lumbar portion of the diaphragm continues to develop, during breathing, it must simultaneously stabilize the proximal insertion of the psoas muscle which pulls in a distal direction when the child supports on the palms and proximal thighs. Also, control mechanisms for both striated- and smooth-muscle esophageal regions are incompletely developed in neonates, participating in reflux mechanism in newborns and infants (Staiano et al. 2007). The combined sphincter function of the esophagus and the diaphragm fully matures in the first 6 months of life.

DEFINITION OF AN IDEAL RESPIRATORY PATTERN FROM A DEVELOPMENTAL PERSPECTIVE

The motor function of the thorax is important for breathing and for postural (stabilization) function. Two types of thoracic movements are distinguished. The first is related to the movement of the spine, the second occurs in the costovertebral joints independently of the movements of the spine. Clinical distinction of such movements plays a fundamental role in the assessment of the quality of respiratory and stabilization functions.

With spinal flexion, the ribs descend and the intercostal spaces narrow. With spinal extension, the entire process is reversed and the thorax positions cranially. The rib cage also moves during thoracic rotation (Kapandji 1992). In a physiologically normal situation, the thorax should be able to move independently of the thoracic spine and vice versa, i.e. the thoracic spine segments straighten without co-movement from the thorax. A disturbance in this function has a marked kinesiological or pathokinesiological significance. This movement, or the positioning of the neutral 'lower' alignment of the thorax with a simultaneous straightening of the spine, depends on the costovertebral articulations, or rib movements. In good health, this posture is observed as early as in a 4½-month-old infant.

During breathing, the ribs elevate and descend around an axis leading from the centre of the head of the rib obliquely and dorsolaterally to the costotransverse joint (Kapandji 1992). The ribs also move with muscle activation during trunk stabilization; therefore, independently of breathing.

Given that the top seven pairs of ribs are attached anteriorly to the sternum by cartilage, their movement is always linked to movement of the sternum. In a normal pattern, the sternum moves anteriorly (Fig. 2.1.1A) rather than cranially (Fig. 2.1.1B), which can be observed in an accessory (upper chest) breathing pattern.

With diaphragm and intercostal muscle activation, the thoracic cavity enlarges anteriorly and, at the same time, laterally as a result of rib curvature. During exertion, the lateral 'opening' of the lower ribs is also accentuated by the contraction of the diaphragm and by its pressure against the internal organs (Fig. 2.1.2). Breathing and stabilization movements are small in the area of the manubrium and first ribs and are greatest in the area of the longest ribs (especially the rib pairs 7 and 8). In a physiologically normal pattern, the sternum moves in an anterior-posterior (Fig. 2.1.1A) direction, which is allowed for by rotation at the sternoclavicular joint. In a non-physiological breathing pattern, involving mainly vertical (craniocaudal) sternal movement (Fig. 2.1.1B), the movement in the sternoclavicular joint is substituted by movement in the acromioclavicular joint during breathing and also during postural stabilization. This alters the position of the clavicles, which become more horizontal. This situation occurs typically in incorrect positioning of the thorax as a result of dominant accessory muscles, especially during their shortening.

Therefore, the initial alignment of the thorax is essential for physiologically balanced breathing and postural stabilization of the trunk. The neutral position, in which breathing and stabilization should occur without excessive activation of accessory muscles (i.e. sternocleidomastoids, scalenes, pectorales) (Lewit 2010) is considered an alignment of the thorax in which the clavicles form a 25–30-degree angle from the horizontal while the thoracic spine is erect, though great individual variation occurs (Todd 1912).

The alignment of the rib cage should ideally correspond to the position of the pelvis (Fig. 2.1.3A, 2.1.3C). The surmise is that when the thoracic spine is erect, the rib cage is positioned parallel to the pelvis and the centrum tendineum of the diaphragm is on a horizontal plane. Such alignment of the thorax allows for the centrum tendineum to act in a caudal direction, as a piston against the pelvic floor (Fig 2.1.3A, 2.1.3C). From a developmental perspective, this harmony and the above-described alignment of the pelvis and the thorax to one another should already be ensured at the age of 4½ months. This is the time when stabilization of the thorax, spine and pelvis in the sagittal plane is completed as a basic prerequisite to locomotor function of the extremities. In later stages, when the child attains quadruped, sitting and standing positions, the child uses the ideal breathing pattern described above, activates the same stabilizing muscle

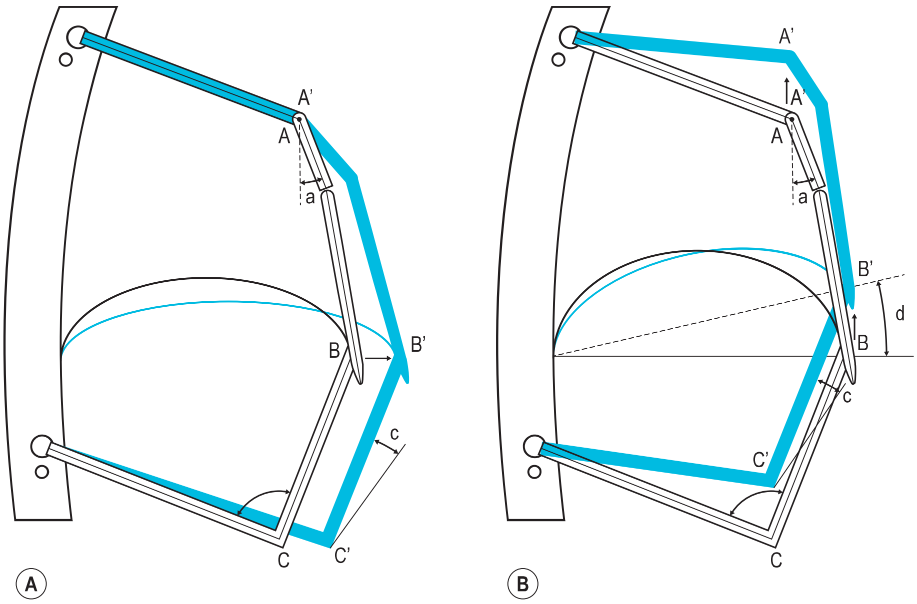

Figure 2.1.1 **A** Optimal 'diaphragmatic' breathing: position of the ribs in transverse plane remains more or less the same during respiratory cycle; widening of the intercostal spaces and lower chest cavity occurs (distance C–C′); movement of the sternum is mainly ventro-dorsal (distance B–B′, 'a' angle); with inspiration the diaphragm descends caudally and flattens while maintaining its position in sagittal plane. **B** Accessory breathing pattern: cranial movement of the whole chest occurs with every inspiration (A–A′ distance, B–B′, C–C′ distance); insufficient widening of the lower chest and intercostal spaces (distance C–C′) and cranial movement of the xyphoid (distance B–B′); diaphragmatic excursion is smaller and as the chest lifts the diaphragm goes into a more oblique position ('d' angle) without the ideal flattening.

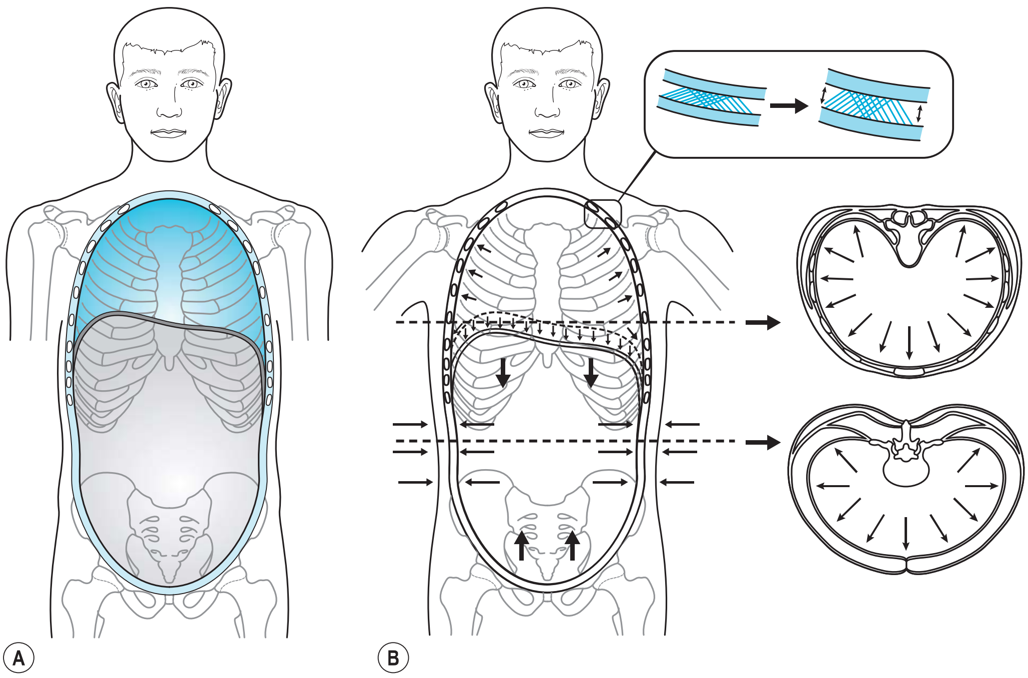

Figure 2.1.2 During exercise or any postural activity, eccentric activity of the stabilizing muscles occurs except for diaphragm and pelvic floor which activate in a concentric manner. The diaphragm descends in a caudal direction, pressurizing intra-abdominal content from above, pelvic floor activates against; muscles of the chest and abdominal wall activate eccentrically like a belt, thus intra-abdominal pressure is increased, stabilizing the spine. Comparing the resting state (**A**), to that of exertion/postural tasks (**B**) the chest and abdominal cavity expand proportionally in ventral, dorsal and lateral directions.

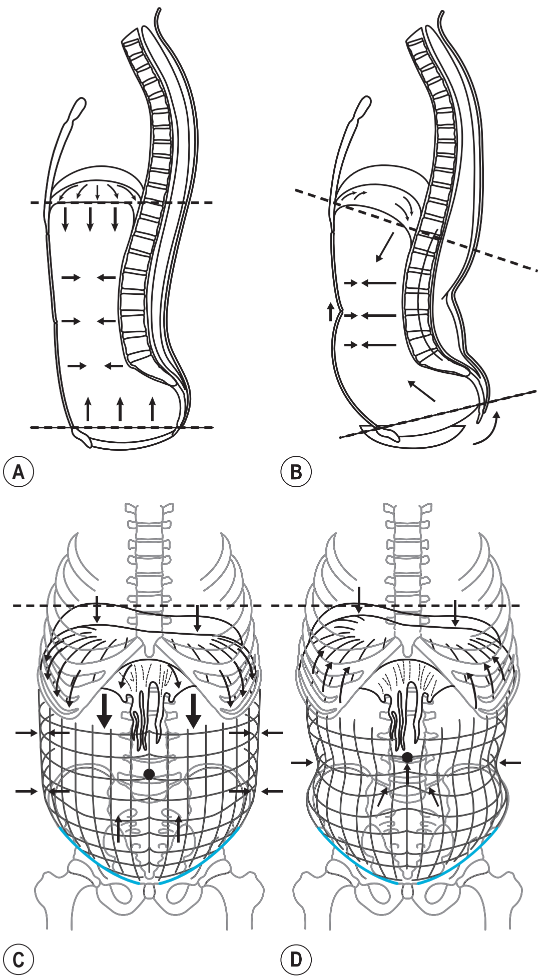

Figure 2.1.3 **A, C** Physiologically balanced coordination between the diaphragm, abdominal muscles and the pelvic floor. **A** Proper alignment between diaphragm and pelvic floor – their axis is almost horizontal and parallel. **C** During postural activities the abdominal cavity expands, diaphragmatic costal attachments are stabilized (small arrows), and the centrum tendineum descends (large arrows). **B, D** Pathological coordination between the diaphragm, abdominal muscles and the pelvic floor. **B** Common type of postural disturbance: anterior pelvic tilt, cranial 'inspiratory' position of the chest, diaphragm and pelvic axis oblique: this malposition does not allow for ideal postural coordination and optimal intra-abdominal pressure regulation, and results in substitutive hyperactivity of the paraspinal muscles. **D** Abnormal muscle coordination during postural activities: abdominal wall 'hollowing', diaphragmatic costal attachments are not stabilized, inversion function of the diaphragm (arrows), and the centrum tendineum remains in a cranial position.

co-activation during exertion and the same mutual alignment between the pelvis and the thorax while the spine is erect.

POSTURE AND POSTURAL FUNCTION OF THE DIAPHRAGM

The function of the diaphragm is usually analyzed from the perspective of vital functions, such as breathing and metabolism. Much less work focuses on its postural function (Hodges & Gandevia 2000a, Hodges & Gandevia 2000b, Kolar et al. 2009, Kolar et al. 2012). Within the context of posture, individual authors analyze the function of the diaphragm from the perspective of symmetrical (balance) functions (Caron et al. 2004), while others focus on assessment in standing (Butler et al. 2001, Caron et al. 2004) or sitting (Takazakura et al. 2004). However, the term *posture* is much broader.

Posture is understood to be an active maintenance of body segments against the action of external forces, from which gravity has the greatest impact. Posture, however, is not a synonym to erect standing or sitting, but rather a component of any position (i.e. straight head position of an infant in prone or LE lifting against gravity in supine), especially of every movement with locomotion. Posture is the main prerequisite for locomotion. Sherrington wrote: 'Posture follows movement like a shadow' (Sherrington 1931). If any movement is broken down into phases, short time segments of a given motion are obtained, or 'frozen phases' (Janda 1972), from which posture can be derived. This involves joint alignment in a static position, which is a component of movement.

Postural stabilization is the active (muscle) maintenance of body segments within the gravitational field and against the activity of external forces, controlled by the CNS. In a static scenario (i.e. sitting, standing), relative joint stability is ensured through muscle activity. This stability allows for resistance against the gravitational force in a given position. Postural stabilization, however, is a component of all movements. During every movement of a body segment that requires force production (i.e. lifting or holding an object, extremity movement against or without resistance, push-off effort, ball throw), a necessary contractile muscle force is always generated to overcome the resistance. It is then transferred to force moments in a segmental pulley system within the human body and elicits reaction muscle forces within the entire muscular system. The biological purpose of this reaction is to enforce the individual movement segments (joints) to achieve the most stable 'punctum fixum' and for the joint segments to resist external forces. The strength of the interconnection between the segments can be, to a certain extent, altered and several anatomical segments in this chain can be interconnected into one unit. The desired strength of the interconnections is achieved by coordinated activity of the agonists, antagonists and other muscle groups. For movement, the trunk needs to be stabilized and, at the same time, sufficient freedom of movement needs to be allowed for in the joints of the extremities. Coordination of concentric, isometric and especially eccentric muscle activity is required to achieve this goal.

No purposeful movement (including extremities) can be executed without stabilization at the insertion of the muscles performing a given movement (in other words, the segment to which the muscles performing the movement attach, needs to be stabilized). For example, hip flexion cannot be performed without stabilization of the spine and the pelvis. A stabilized spine and pelvis ensure stabilization of the hip flexor tendons (rectus femoris, iliopsoas, sartorius) (Fig. 2.1.4) and protect the segment in this way from being overexerted during movement (Kolar et al. 2010, Kolar et al. 2012).

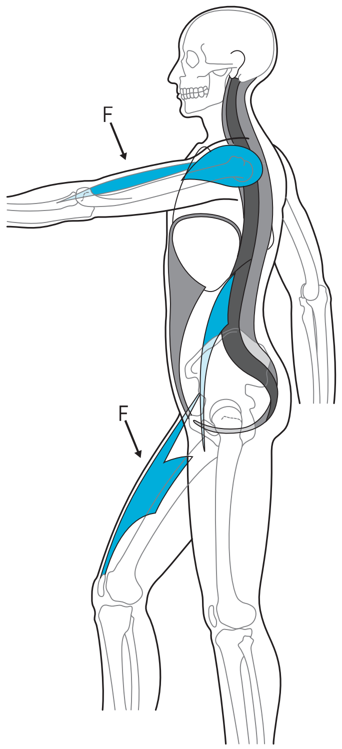

Figure 2.1.4 The muscles stabilizing the shoulder, pelvic girdle and spine. Under normal physiological conditions, the stabilizers: in grey – the diaphragm, the pelvic floor, all the sections of the abdominal wall and spinal extensors – automatically activate prior to purposeful movement (e.g. hip flexion provided by the muscles in blue: m. iliopsoas, rectus femoris, sartorius) to establish a stable base ('feed-forward mechanism'). In normal subjects, the stabilizing function of the trunk (in grey) muscles control shear of lumbar segments during hip flexion. Well-balanced activity between the deep neck flexors and spinal extensors is necessary for stabilization in the cervical and upper thoracic region. F, force (extremities activate against gravity or other force).

Movement in the segment (in this case, a hip joint) then includes spinal extensors, abdominal muscles, diaphragm, pelvic floor, etc., which prevent movement in the insertional region of the flexors. The activity of the stabilizing muscles generates activity in other muscles that are insertional related. These muscles then ensure stabilization in other segments. This mechanism leads to functionally interlinked stabilization of the entire trunk during movement. Segmental stabilization is biomechanically interconnected and depends on coordinated muscle activity controlled by the CNS. From the perspective of ontogenesis, these principles are already fully utilized at 5 months of age. The coordination of trunk stabilization, or the quality of stabilizing muscle coordination, which a child forms within the first few months of life, is then used for the rest of their life. It is therefore essential for early ontogenetic development to occur in an ideal pattern rather than for a child to encode a pathological pattern from the beginning.

The fact that breathing accompanies each movement also influences postural function. Breathing movements are an integral component of postural functions. Breathing influences not only body posture but, through its rhythmical activity, also neuron excitability (Rekling et al 2000). With a few exceptions, an inspiration triggers excitation of most muscles while expiration is inhibitory. These findings are often used during rehabilitation treatment (Lewit 2010).

It has been empirically found and later experimentally demonstrated that the diaphragm is tonically activated when lifting objects (Hemborg et al.1985). From a kinesiology perspective, it is important that the diaphragm contracts prior to activation of the upper and lower extremity muscles (or any locomotion). Various authors (Hodges et al 1997, Kolar, et al 2012) state that stabilization of the pelvis and lumbar spine is ensured prior to any actual movement of the extremities. The CNS has to anticipate purposeful movement and automatically position the body to achieve the desired outcome.

Hodges and Gandevia (2000a) observed EMG activity of the diaphragm and muscles of the shoulder girdle during alternating movements of the upper extremities (UEs). EMG activity of the diaphragm occurs approximately 20 ms prior to activation of UE movement without taking into consideration the phase of the breathing cycle, therefore including expiration. As a result, the diaphragm shortens (shown by an ultrasound) and the transdiaphragmatic pressure P_{di} (the difference between the intra-pleural and intra-abdominal pressures) increases. This muscle synergy stabilizes the trunk and forms a foundation that is a prerequisite for all movement activities (Hodges et al 1997).

Since stabilization function is integrated in nearly all movements, the effects of internal forces are recognized not only due to their quantity, but also from their marked stereotypical repetition. If they elicit non-physiological, unbalanced loading, it is only a matter of time as to when problems will emerge, including morphological changes. It is also important that while a targeted movement is freely controlled, the reactive stabilization functions occur automatically and without volitional control, therefore, without awareness. A number of studies document coordinated synergy of the diaphragm, transverse abdominis, pelvic floor and the multifidus muscles during postural activity (Hodges & Gandevia 2000b). However, this synergy is not under full volitional control and modifiable. Therefore, the diaphragm, controlled by the CNS, assists in ensuring postural body control. The activity of motor neurons of the phrenic nerve is organized in such a way that the diaphragm simultaneously contributes to respiration as well as body stabilization and other nonventilatory behaviours (Mantilla & Sieck 2008).

The motor activity of the diaphragm has three components: tonic, phasic coordinated with a breathing cycle and phasic coordinated with movements of the trunk and/or the extremities (Hodges & Gandevia, 2000a). The dome of the diaphragm flattens during inspiration and during the trunk's postural stabilization function, or independent of breathing (Fig. 2.1.3C). The degree of flattening depends on the quality of the breathing pattern and postural function (Kolar et al 2012) (Fig. 2.1.5, Fig. 2.1.6).

In a physiologically normal situation, during postural activity related to breathing, diaphragm excursion and its flattening are more accentuated when compared to breathing at rest (Kolar et al 2010). By its caudal descent, or flattening during inspiration and during postural exertion, the diaphragm increases pressure on the internal organs (works as a piston) and the increased intra-abdominal pressure acts against the abdominal and pelvic floor musculature. The activity of the abdominal muscles stabilizes the diaphragm's insertions to the ribs (see Fig. 2.1.2B, Fig. 2.1.3A and Fig 2.1.3C).

During inspiration and postural activation, an eccentric expansion of the abdominal wall occurs so that the volume of the abdominal and thoracic wall increases (Fig. 2.1.2). When the abdominal wall adequately expands, its volume is maintained isometrically. In an ideal scenario, this 'eccentric-isometric' muscle activity is proportional to the degree of exerted muscle work and to the demands of the motion. If a greater muscle activity is needed, the diaphragm flattens; however, its excursions during breathing are smaller. Therefore, the diaphragm in this situation favours postural function. During significant exertion, a person usually holds their breath to increase postural stabilization and the diaphragm is primarily activated for its stabilization function.

The flattening of the dome of the diaphragm leads to changes in the volume and shape of the rib cage and

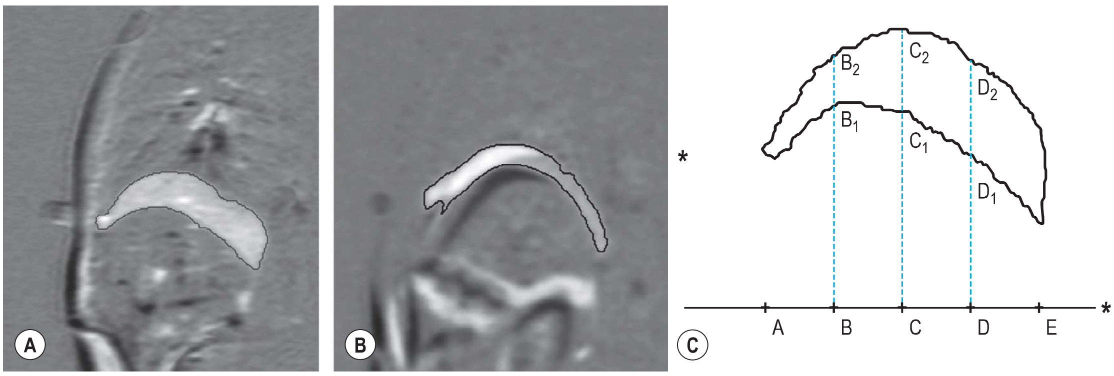

Figure 2.1.5 **A** Subtracted magnetic resonance image of the diaphragm excursions in the most caudal (inspiratory) and cranial (expiratory) diaphragm positions during tidal breathing in a healthy person. **B** A subtracted image of the diaphragm excursions in the most caudal (inspiratory) and cranial (expiratory) diaphragm positions during tidal breathing in a patient with chronic low back pain. Note more cranial and domed position of the diaphragm compared to healthy individual. **C** Schematic description of three diaphragmatic points (B, C and D) used for diaphragm excursion calculations. The following six distances (in mm) were obtained by measuring the distance between the horizontal baseline in both expiratory and inspiratory diaphragm positions. Diaphragm excursion points: B_1 to D_1 were derived from the inspiratory diaphragm positions obtained from MRI images; B_2 to D_2 were derived from expiratory diaphragm positions obtained from respective MRI images. The inspiratory diaphragm position is designated by points B_1, C_1 and D_1. The expiratory diaphragm position is designated by points B_2, C_2 and D_2. Total diaphragm excursion is designated by the distance from the lower to the upper curve along points B_1 to B_2, C_1 to C_2, and D_1 to D_2. *Reproduced with permission from: Kolár P, Šulc J, Kyncl M, et al. Postural function of the diaphragm in persons with and without chronic low back pain. J Orthop Sports Phys Ther 2012;42(4):352–362, Epub 21 December 2011. doi:10.2519/jospt.2012.3830.*

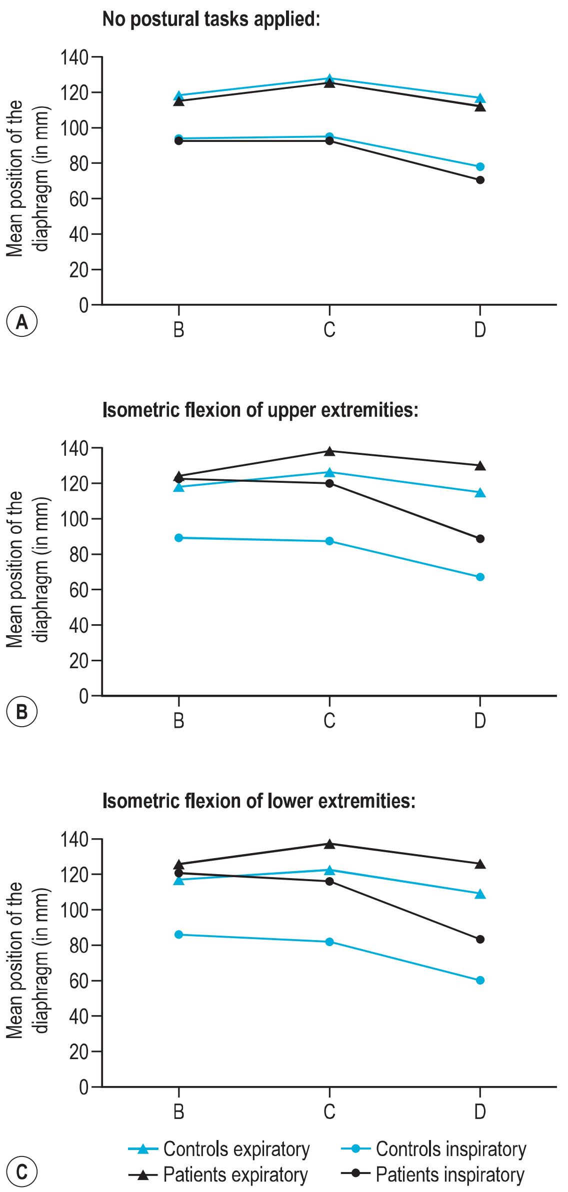

Figure 2.1.6 **A** Inspiratory and expiratory positions of the diaphragm during tidal breathing for patient and control groups. Position and shape of the diaphragm is similar in both groups. (B, C, D points in the graphs correspond with the points in Fig. 2.1.5C). **B** Inspiratory and expiratory positions of the diaphragm during tidal breathing with isometric flexion of the upper extremity in the patient and control groups. Note a higher (more cranial) position of the diaphragm and a reduced diaphragm excursion in the patient group (black lines are higher and the distance between the black lines is smaller than the distance between the blue lines). In addition, a steeper slope in the middle-posterior diaphragm in the patient group occurs. **C** Inspiratory and expiratory positions of the diaphragm during tidal breathing with isometric flexion of the lower extremity in the patient and control groups. Cranial position and reduced diaphragm excursion as well as steeper slope in the posterior (lumbar) section of the diaphragm is even more pronounced in a patient group during lower extremity activation. *Reproduced with permission from: Kolar P, Sulc J, Kyncl M, et al. Postural function of the diaphragm in persons with and without chronic low back pain. Orthop Sports Phys Ther. 2012 Apr;42(4):352–62. Epub 2011 Dec 21.*

abdominal cavity. The thoracic cavity expands anteriorly and, as a result of rib curvature, also laterally (Fig. 2.1.2). During normal movement, the sternum moves anteriorly with movement occurring in the sternocostal joints (Fig 2.1.1A). The content of the abdominal cavity is non-compressible (with the exception of approximately 100–300 ml of air). This means that, during inspiration or during postural activity of the diaphragm, the organs of the abdominal cavity shift caudally and the abdominal wall expands in a cylindrical fashion in all directions. This requires synchronized eccentric activity of all muscles inserting into the thorax and muscles of the abdominal wall (see Fig. 2.1.2B, Fig 2.1.3A and Fig. 2.1.3C). Only the pelvic floor and diaphragm work concentrically against the content of the abdominal cavity.

During normal inspiration and also during stabilization related to the flattening of the dome of the diaphragm, the pectorales, scalenes, sternocleidomastoids, all abdominal muscles, quadratus lumborum, spinal extensors and hip external rotators must accommodate the expansion of the thoracic, abdominal and pelvic cavities by their eccentric activity (Fig. 2.1.7). Once the dome of the diaphragm fully flattens in coordination with the eccentric activity of the muscles of these cavities, an isometric or stabilization contraction of these muscles occurs allowing for movement of the extremities. The eccentric activity of the muscles inserting into the thorax and pelvis also increases their excitability. This allows for a greater stabilizing force of the trunk. This pattern is quite obvious in power lifters, sumo wrestlers, Samurai fighters and other athletes who need to produce maximal force, as well as, technical precision during their performance. The quality of the described stabilization of muscle coordination is essential for prevention of overloading and for the onset of secondary vertebrogenic pain syndromes. A similar postural respiratory pattern can be elicited during Vojta's reflex locomotion and can also be observed during physiologically normal ontogenesis after the 4th month of life (Vojta & Schweizer 2009).

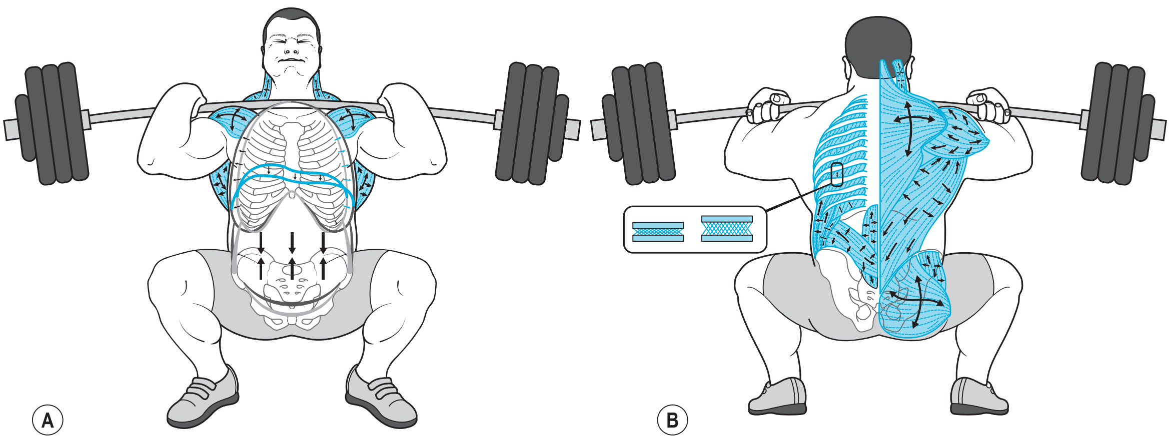

Figure 2.1.7 Eccentric activation of the stabilizers during postural tasks. The timing is important: stabilizing muscles must first activate eccentrically, expanding the trunk's volume, and then hold the stabilizing activation isometrically (or even concentrically). Only the diaphragm and the pelvic floor muscles are concentrically activated from the start.

PATHOLOGICAL RESPIRATORY POSTURAL PATTERN

During non-respiratory or strictly postural activity, the diaphragm does not change its shape in a typical fashion. It does contract and flatten, but non-homogenously (the diaphragm does not activate as one muscle but rather its individual parts can be active at different times). This pattern also differs in healthy individuals and in patients with chronic low back pain. Dynamic MRI demonstrated that patients with chronic low back pain and abnormal morphological findings in the lumbar spine, show greater flattening of the lumbar portion of the diaphragm when compared to a healthy population (Kolar et al 2012) (see Figs. 2.1.5 and 2.1.6).

From clinical experience, it is known that a marked individual difference exists in the extent of respiratory and non-respiratory movements of the diaphragm. Individuals who do not demonstrate sufficient ability to contract the diaphragm during trunk stabilization pose a greater risk of low back pain (O'Sullivan et al 2002). Chronic abnormal loading of the spine as a result of imbalance of internal muscle forces acting on the spine during postural stabilization is seen as the main reason.

Smaller flattening of the dome of the diaphragm during postural activity and also an imbalance in its activation are seen as the main components of insufficient stabilization of the diaphragm (Boyle et al 2010). In this situation, the diaphragm loses its function as a piston (see Figs 2.1.3B and 2.1.3D). The reason for a smaller flattening of the diaphragm can either be weakness of the diaphragm, which has been demonstrated by measuring maximal respiratory muscle strength during inspiration in patients with chronic back pain, disrupted intra-muscular coordination or abnormal coordination of the diaphragm and other postural-respiratory muscles (Kolar et al 2012, Boyle et al 2010).

In a pathological scenario (see Figs 2.1.3B and 2.1.3D), during postural activity, an inverse (paradoxical) function of the diaphragm can be observed, during which the centrum tendineum is in a fixed alignment and no stabilization in the area of the lower ribs occurs. During diaphragm activation, the lower ribs are elevated cranially and the intercostal spaces narrow as a result of stretching the diaphragm's insertions to the ribs.

Through the sternum, the cranial movements are transferred to the upper ribs that are also elevated by activity of the accessory inspiratory muscles (Fig. 2.1.1B). In such individuals, hypertrophy of the paravertebral muscles (Fig 2.1.3B) of the lower thoracic and upper lumbar spine can often be observed, where they over-activate in challenging situations as a compensatory mechanism for posturally insufficient function of the diaphragm. In addition, in such individuals, the postural activity of the diaphragm is disproportional to the lumbar portion, which is mainly being utilized (Fig. 2.1.6). An abnormal stabilization function always goes hand in hand with a dysfunctional breathing pattern. Cranial movement of the ribcage with an inward drawing of the lateral intercostal spaces during inspiration is a typical pathological movement (Fig 2.1.3D).

VISCERAL AND SPHINCTER FUNCTIONS OF THE DIAPHRAGM

The visceral and sphincter functions of the diaphragm are additional and often forgotten functions of the diaphragm. The diaphragm influences the internal organs in two important ways; first, during the diaphragm's pressure on the internal organs within the breathing and postural functions as described above and, second, during the diaphragm's interplay with the lower esophageal sphincter (LES).

The diaphragm is a true visceral muscle, especially its crural portion. This portion phylogenetically develops in amphibians as a ring-like muscle around the esophagus. During evolution, this musculature merges with the developing diaphragm giving rise to the crural portion of the diaphragm. This is supported by ontogenesis and embryonic development of the human diaphragm because the crural portion develops from esophageal structures, specifically the mesesophagus (Langman 1981).

The diaphragm is also a skeletal muscle partially innervated by the vagus nerve. It is particularly the crural portion of the diaphragm that is innervated from the nucleus of the vagus nerve (Young et al 2010). Given this innervation, the crural portion of the diaphragm is in perfect co-activation with swallowing, during which the crural portion needs to relax to allow for the transport of the bolus to the stomach. In contrast, with an increasing intra-gastric pressure, activation of the crural portions needs to occur as well as an increased pressure at the LES region, which prevents the return of the stomach content to the esophagus (Liu et al 2005). Therefore, the diaphragm is actually two muscles in one anatomical unit (Pickering & Jones 2002) with three main functions: respiratory, postural and visceral.

Pressure activity of the diaphragm and the effect on internal organ function

Visceral movement and peristalsis

During a breathing cycle, a rhythmic compression of the abdominal cavity occurs and leads to a cyclical movement of the internal organs. During inspiration, almost all internal organs of the abdominal and retroperitoneal areas shift several centimetres in a caudal direction (Xi et al 2009). This organ movement and the pressure activity of the diaphragm partially contribute to the transport of food and digestive juices. In this way, the diaphragm assists in digestive processes and significantly contributes to peristalsis and food propulsion.

Birth

The size of the fetus influences the position of the diaphragm, which gradually shifts cranially during pregnancy (fetal growth). The diaphragm, as a result of pressure and a change in position, becomes functionally less active, which leads to an increased activity of the accessory inspiratory muscles. This can lead to overuse, hypertonus and pain, especially in the cervical region. Decreased diaphragm function is also manifested by sphincter dysfunction (see below). Therefore, reflux episodes significantly increase in pregnant women, which can lead to an onset of gastro-esophageal reflux disease (GERD) (Rey at al 2011). In contrast, the pressure action of the diaphragm is an important force (with an optimal vector) necessary for fetal progression and expulsion during the second phase of delivery.

Defecation

Similarly to postural trunk stabilization, correct co-activation (timing, synergy) between the diaphragm, abdominal musculature (especially transverse abdominis) and the pelvic floor is essential during defecation. Therefore, postural dysfunction also presents in problems with defecation (constipation). Weakness of an abdominal brace resulting in limited defecation propulsion is one of the most frequent disturbances in patients with constipation. Deficit in co-activation can also be seen in dyssynergic defecation (Rao 2008), in which a paradoxical contraction of the pelvic floor and drawing in of the abdominal wall and the lower ribs (inversion function of the diaphragm – see above, Fig. 2.1.3D) occur during a defecation attempt. This dysfunction serves as an example of a deficit in co-activation of abdominal and pelvic floor musculature with the diaphragm playing an important role.

Vomiting

The diaphragm also plays an important role during vomiting, when an interesting functional division of the sternal and crural portions of the diaphragm can be observed. The process occurs as follows. Initially, the entire diaphragm is activated (sternal and crural portions) and presses on the stomach, which significantly increases the intra-gastric pressure. Then, the crural portion is inhibited, but the sternal portion continues in large rhythmical contractions and the gastric contents are pumped into the esophagus. During vomiting, the posterior aspect of the diaphragm is inhibited (which opens the cardium) and the anterior aspect generates the force with such vector to allow retrograde movement of the vomitus back to the esophagus and the mouth.

The diaphragm's role as a lower esophageal sphincter

The lower esophageal sphincter (LES) is an essential structure preventing movement of the stomach content back into the esophagus. It prevents, in this way, the onset of GERD. The incidence of GERD continues to grow (Sonnenberg 2011) and the disease manifests itself by many associated symptoms, including heartburn, regurgitation, retrosternal pain, etc. with subsequent complications of esophagitis, bronchial asthma, Barret's esophagus and esophageal cancer. The LES is formed by two components: the circular musculature of the esophagus and the crural portion of the diaphragm, which forms an anatomical loop in the LES region. The crural portion of the diaphragm has specifically been shown to be the main component of LES (Mittal et al 1987). Diaphragm dysfunction is viewed as one of the essential causes of GERD (Pandolfino et al 2007).

The diaphragm is considered to be an external esophageal sphincter and, for example, during the respiratory cycle will demonstrate regular pressure fluctuations (pressure increase during an inspiratory phase) in the LES region, which can be verified by manometric observation. Since the diaphragm is simultaneously a respiratory and postural muscle, a dysfunction in these areas reflects also in sphincter dysfunction, which is an important component in the diagnosis and treatment of GERD. Many patients with GERD, therefore, demonstrate not only sphincter dysfunction, but also a combined respiratory-postural dysfunction, which is manifested by a tendency toward spinal pathologies, altered postural activity and stabilization (especially in the lumbar, cervical and thoracolumbar regions) and an altered breathing pattern, in which the activity of the accessory inspiratory muscles dominates over the diaphragm. Decreased occlusion pressures (the force of respiratory muscles) during inspiratory as well as expiratory manoeuvres (PI_{max} and PE_{max}) was the dominant finding in our sample of patients with GERD. In short, it can be stated that patients with GERD are also 'respiropathics' as far as the force of the respiratory musculature is concerned (Bitnar et al 2010a).

During a normal inspiratory manoeuvre (PI_{max}), a pressure decrease is observed in the thoracic portion of the esophagus as a result of intrathoracic underpressure. In contrast, a large increase in pressure is observed in the abdominal portion of the esophagus (LES region) caused by contraction of the diaphragmatic crura. In patients with GERD, this increase is smaller and the sphincter is weaker. Also, in patients with a significant reflux, a paradoxical reaction of the diaphragm can almost be observed during PI_{max} manoeuvres, in which the crural portion of the diaphragm does not contract during maximum inspiration. Rather, the crural portion paradoxically weakens, which is manometrically observed by a paradoxical decrease in pressure in the sphincter and an expansion of the gastro-esophageal junction (Bitnar et al 2010b).

In patients with GERD, however, in addition to the diaphragm's (or respiratory musculature) strength, it is important to also monitor the quality of the breathing pattern (breathing mechanics) because an incorrect respiratory pattern is the most common dysfunctional pattern in patients with such disease. It is important that a therapeutic change in breathing pattern with facilitation of diaphragmatic breathing led to correction of LES hypotonus, which can also be observed during manometric examination (Bitnar at al 2010a, Bitnar at al 2010b, Smejkal et al 2010).

Breathing pattern correction is then the basic therapeutic intervention within conservative treatment in patients with GERD. During breathing alteration, or during facilitated abdominal (diaphragmatic) breathing, the LES pressure significantly increases, which is caused by activation of the diaphragmatic crura without a change in respiratory volumes (the amount of air ventilated). This has been demonstrated by spirometry (Bitnar at al 2010a, Bitnar at al 2010b, Smejkal et al 2010).This means that a change in the quality of the breathing pattern (with greater participation of the diaphragm and lesser activation of the accessory inspiratory muscles) positively influences the ability of the LES. This qualitative change leads to restoration of the anti-reflux barrier.

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