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FACULTEIT GENEESKUNDE EN LEVENSWETENSCHAPPEN

master in de revalidatiewetenschappen en de kinesitherapie

Masterproef deel 1

The role of the diaphragm in trunk stability: a systematich overview of the measurement tools

Promotor :
dr. Lotte JANSSENS

Josefine Smeets , Eva Schalley

Eerste deel van het scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie

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The role of the diaphragm in trunk stability: a systematic overview of the measurement tools

Research question: Which are measurement tools to assess the core stabilizing function of the diaphragm?

Highlights:

- There are three direct methods to measure the core stabilizing function of the diaphragm: electromyography, ultrasound imaging, magnetic resonance imaging and seven indirect methods: intra abdominal pressure, maximal inspiratory pressure, inspection or palpation of breathing patterns and postural control measures during respiratory disturbance.
- The core stabilizing function of the diaphragm has been assessed (indirectly) through several patient populations, among which low back pain, sacroiliac joint pain, chronic obstructive pulmonary disease, asthma, chronic ankle instability, stroke and tetraplegia using the measurement tool described above.
- In healthy subjects (or patient populations), postural tasks e.g. active straight leg raise, lifting task, rapid upper limb movements in combination with the appropriate measurement tool, are used to investigate the core stabilizing function of the diaphragm.

Students: Josefine Smeets and Eva Schalley

Promoter: Dr Janssens Lotte

Research framework

This literature study fits within the domain of the musculoskeletal rehabilitation and was completed as a duo master thesis, part one.

Due to previous studies, it is not strange anymore when the diaphragm is presented as an important component of the stabilizing mechanism of the trunk during everyday life, while carrying out postural tasks. Still, the diaphragm is not yet fully incorporated in clinical investigation, for diagnosis or in rehabilitation, e.g. in low back pain there could be an impaired contribution of the diaphragm to trunk stability. However, it's not that easy to measure or visualize the diaphragm, because it's laid deep in the thorax, covered by some other trunk/respiratory muscles and the rib cage. This is perhaps why therapists in practice do not know how to accurately measure and investigate the diaphragm. Therefore, the purpose of this study was to give a systematic overview of measurement tools, which investigates the core stabilizing function of the diaphragm.

This literature research is an isolated study accomplished by two students of Hasselt University under supervision of promoter Dr Janssens Lotte, within the time period of October 2016 till June 2017. A central format was used for the draft of the literature study. The research question was established in consultation with the promoter and the two students. Hereafter, both students completed the literature study independently. When there was disagreement between the two students about the research results, it was discussed, followed by an agreement. Afterwards the two students together wrote the review.

The second part of this review consists of a research protocol, which was established by the two students from Hasselt University. The aim is to investigate the thickness of the diaphragm and intercostal muscles with ultrasound imaging in supine lying and during unilateral versus bilateral active straight leg raise. Furthermore, the correlation between this thickening and the maximal inspiratory pressure will be assessed. This research has not yet been conducted. However, the data collection already took place at Fontys University in cooperation with two students from this University, who also did research about the same topic mentioned above. The two students from Fontys University took care of the participant recruitment. The data will be analyzed in the course of next year, in the context of master thesis part two.

In this duo master thesis, both students delivered an equal effort to complete this literature study.

Content table

1. Abstract

Background: The role of the diaphragm in core stability is often hypothesized in many patient populations. However, objective measurement of this role is often lacking. Since the diaphragm is a profound muscle, it's hard to evaluate its core stabilizing function in practice. Thus, the question is, which measurement tools can be used in certain circumstances or patient groups to map the postural activity of the diaphragm.

Methods: The consulted databases for the research strategy were PubMed and Web of Science, which generated a total of 523 articles. After screening, 42 articles were included in this systematic review.

Results: Measurement tools involved electromyography (EMG), ultrasound imaging (US), magnetic resonance imaging (MRI), intra-abdominal pressure (IAP), maximal inspiratory pressure (MIP), inspection or palpation of breathing patterns and postural control measures during respiratory disturbance.

Discussion and conclusion: EMG and IAP are the most flexible methods because all postural tasks can easily be performed while measuring. However, these are invasive methods and therefore less attractive in physiotherapy. This in contrast with MRI and US, which are not invasive, but not all postural tasks can be performed. Other useful measurement tools in practice are MIP and inspection or palpation of breathing patterns when there is little infrastructure available. Additionally, assessment of patient populations (e.g., COPD), compared to healthy controls is also a method to (indirectly) evaluate the role of the diaphragm in core stability. Still, there is further research needed whether e.g. US is a valid measurement tool to use in this context for diagnosis and rehabilitation.

Purpose of this research: The aim is to gain a proper overview of measurement tools, which can be used to consequently gain insight in the actual role of the diaphragm in core stability.

Purpose of MP2: The aim is to investigate the thickness of the diaphragm and intercostal muscles with ultrasound imaging (US) in supine lying and during unilateral versus bilateral active straight leg raise (ASLR). Furthermore, the correlation between this thickening and the MIP is assessed.

Operationalizing research question: Is thickening of the diaphragm visible through US during a postural task, e.g., ASLR?

Key words: diaphragm, respiratory muscles, postural function, trunk stability, trunk control, ultrasound, maximal inspiratory pressure

2. Introduction

The diaphragm is a skeletal muscle that has a vegetative (respiration), as well as a somatic function (postural control). Because only the somatic function of the diaphragm is relevant to physiotherapy, this review will continue focusing only on this latter function. In healthy individuals, a close collaboration of the diaphragm, transversus abdominis, erector spinae and pelvic floor provides an increase of intra-abdominal pressure (IAP). In addition to this, It has been shown that the IAP is positively correlated with increased stiffness of the spine (Shirley, Hodges, Eriksson, & Gandevia, 2003). Thus, The diaphragm contributes to spinal stiffness, which in turn helps to ensure postural control. Moreover, P. W. Hodges, Butler, McKenzie, and Gandevia (1997) have demonstrated that the diaphragm contracts prior to the upper limb muscles in rapid movement.

However, it is hard to map the activity of the diaphragm because of its deep position in the thorax. Therefore, it's difficult to involve this muscle in a physiotherapeutic diagnosis. Anatomically, the diaphragm consists of a muscle part and a central tendon part. It has three origins, with the central tendon as insertion. Pars costalis origins on rib 7-12, which alternates with the origin of the transversal abdominal muscle. Pars lumbalis origins on the lumbar spine, with a medial crus (corpus L1-L4) and a lateral crus (lateral tendon arc, through which the psoas muscle and quadratus lumborum muscle pass). Pars sternalis origins on the xiphoid process. Furthermore, there are some vital structures crossing the diaphragm, among which the vena cava inferior, the esophagus, the phrenic nerve and the aorta. Considering the cross section of the respiratory chest musculature, the most superficial layer consists of the external intercostal muscles, which are oriented cranial-dorsal to caudal-ventral and function as inspiratory muscles. Further profound lay the internal intercostal muscles, which are oriented cranial-ventral to caudal-dorsal and function as expiratory muscles. The most profound layer consists of the diaphragm. (Platzer W., 2009).

Dysfunctions of the core stabilizing (or postural control) function of the diaphragm are observed in different populations. Patients with chronic obstructive pulmonary disease (COPD), especially those with decreased inspiratory muscle force, have decreased postural stability (Janssens, Brumagne, McConnell, Claeys, et al., 2013). Thus, it is expected that the core stabilizing function of the diaphragm of this population be disturbed. In addition, a disturbed postural function of the diaphragm can be a contributing factor in patients with low back pain. When performing a postural task, patients with low back pain will use their diaphragm abnormally. The movement of anterior, medial and costal part of the diaphragm is limited, which results in an asymmetric activation. Therefore, the diaphragm contraction is less powerful, which is assumed to cause a reduced IAP (Kolar et al., 2012). Moreover, it's stated that strategies of the central nervous system are changed in patients with chronic pain syndrome (P. W. Hodges, Cresswell, Daggfeldt, & Thorstensson, 2001) and that individuals with low back pain have an altered breathing pattern during heavy and nonheavy activity (N. Roussel et al., 2009). Furthermore, stroke patients with decreased inspiratory muscle force have disturbed trunk control (Jandt, Caballero, Junior, & Dias, 2011). Lastly, changes in the contractility of the diaphragm could be the cause of ankle instability due to diaphragm dysfunctions and central nervous system changes (Terada, Kosik, McCann, & Gribble, 2016). When taking all of this in account, it would be relevant as physiotherapist to assess the core stabilizing function of the diaphragm in clinical practice.

The purpose of this literature search is to clarify the possible measurement tools to assess the role of the diaphragm in core stability. The aim is to classify the measurement tools by quality and characteristics and to promote the use of diaphragmatic measurement tools in clinical settings.

3. Method

3.1 Research question

Which are measurement tools to assess the core stabilizing function of the diaphragm? This research question is merged in the following PICO.

P: Patients, healthy persons and animals
I: Measurement of the core stabilizing function of the diaphragm
C: /
O: Core stability

3.2 Literature search

For the literature search Pubmed and Web of Science were consulted. On the one hand terms to describe muscles of respiratory function were used and on the other hand terms to describe postural function. Terms that didn't give more hits were filtered out. The final terms used are:

(Respiratory muscles [MeSH Terms] OR diaphragm [MeSH Terms]) AND ((postural function) OR (trunk stability) OR (trunk control))

Additionally, specific authors known to be experts in this field were searched (Smith MD AND Hodges PW). Furthermore, the references of the included articles were screened for more relevant articles.

In June, the databases were searched with the same terms, to check if any relevant studies were added.

3.3 Selection criteria

Included studies were observational and experimental studies, which observed the stabilizing role of the diaphragm in all populations, even if it was not the main purpose of the study. The studies had to be written in English or Dutch. Studies were excluded when only the respiratory function of the diaphragm (versus the core stabilizing function) was assessed. Furthermore, non-relevant studies were excluded involving surgical techniques in the abdomen or thorax cavity involving the diaphragm and medical studies: effects of drugs on the respiratory system, hysteroscopic sterilization methods, purely neurological studies without core stabilizing component, and anatomical descriptions of the diaphragm. Studies were not filtered on study design, except for other reviews, which were excluded. Two independent reviewers performed the selection. Animal studies relevant to the research question were included. Studies about rather indirect measurement of the diaphragm, for example intra-abdominal pressure, were included. Studies who reported posture as 'spinal curvature' instead of 'postural control' were excluded. In the doubt cases, a third reviewer made the final decision.

3.4 Quality assessment

For the quality assessment of observational studies, 'the STROBE statement - checklist of items that should be included in reports of observational studies' (http://www.strobe-statement.org) was used. For the assessment of experimental studies, the 'NICE methodology checklist: randomised controlled trials' (https://www.nice.org.uk) was used.

Two independent reviewers, who came to an agreement afterwards, completed the quality assessment. There were no studies excluded after the quality assessment, but limitations were considered in the discussion.

3.5 Data extraction

The following parameters were extracted from the selected articles: Population, aim of the study, description of measurement tool and results of the study. Eventually the parameter 'description of measurement' was most important to answer our research question.

4. Results

4.1 Results study selection

In December 2016 the search strategy gave 345 hits in PubMed and 194 hits in Web of Science. In June 2017 this gave 347 hits in PubMed and 202 hits in Web of Science. Additional separate search for Smith MD and Hodges PW gave 11 hits in PubMed as well as in Web of Science, which was the same in December 2016 and June 2017. After filtering out the double ones, this summed up to a total of 513 articles in December 2016 and 523 in June 2017, which were searched for title and abstract. (Attachments: Table 1)

Reasons of exclusion were surgery / medical studies (e.g., research on the effects of drugs on the respiratory system, hysteroscopic sterilization methods, neurological studies without core stabilizing component, anatomical descriptions about the diaphragm), no assessment of the diaphragm, no abstract or full text available, studies only about respiratory function (so not about the postural task) of the diaphragm, cadaveric studies, other language than Dutch or English, and studies about spinal curvature. (Attachments: Table 2)

Finally, after application of the selection criteria, a total of 41 included articles were reached in December 2016, plus one article from June 2017. These articles contained cross-sectional studies, case-controls, and one RCT. (Attachments: Figure 1). For one relevant study (Skladal & Ruth, 1978) there was no access to the full text. Therefore, it was excluded. Also, after closely reading the methods in the full text of one study it was excluded because it did not truly measure the core stabilizing function of the diaphragm (Kweon, Hong, Jang, Ko, & Park, 2013). Screening of the references from included studies gave no extra relevant studies, probably because of the extensive search strategy.

4.2 Results quality assessment

One RCT was assessed with the ‘NICE methodology checklist’ and 41 observational studies were assessed with the ‘STROBE statement checklist’. No study was excluded after quality assessment.

4.3 Results data-extraction

4.3.1 Direct methods

4.3.1.1 Electromyography (EMG)

Following studies (n= 12) examined the role of the diaphragm in core stability with EMG.

Gandevia et al. (1990) assessed the degree of activation of the diaphragm, intercostal, accessory and abdominal muscles during postural tasks (e.g., flex the trunk in supine position and simultaneously lift the legs against resistance) and respiratory maneuvers (e.g., inspiratory efforts against a closed airway, expulsive efforts with the glottis open and expulsive efforts with glottis closed), this by using phrenic nerve stimulation and motor cortex stimulation. EMG activity of the diaphragm was measured with a multi-lumen gastro-esophageal catheter and EMG activity of trunk muscles with surface or intramuscular electrodes. Results showed greater EMG activity of abdominal and intercostal muscles during trunk flexion than during maximal expulsive efforts.

Segizbaeva et al. (2013) studied EMG activation of respiratory muscles, in healthy subjects, when performing voluntary inspiratory maneuvers during different body positions (standing, sitting, right-sided and left-sided lying, supine). Similar EMG activity of the diaphragm was found in all body positions.

Kolar et al. (2009) measured EMG activity of the diaphragm with intramuscular electrodes, in healthy subjects, to prove that the recorded diaphragm movement was the result of active diaphragm contraction. These measurements took place firstly during tidal breathing and secondly while performing an exercise sequence, the participants were holding their breath at the end of expiratory tidal breathing. Next the subjects were instructed to pressurize and expand the abdominal wall while directing the IAP caudally to the pelvic floor (this stiffens the spine and stabilizes the torso, allowing for increased resistance against internal or external loading or perturbation). Then the subjects were instructed to draw in the abdominal wall. The results showed that the diaphragm is activated independently of respiration. Thus, it's not only a breathing muscle.

Hodges et al. (2001), Hodges et al. (2000), Hodges et al. (2000), Hodges et al. (1997) and Sinderby et al. (1992) all used limb movement as postural task. Hodges et al. (2001) studied whether postural activity of the diaphragm changed when respiratory drive increased with hypercapnoea. The diaphragm and other trunk muscles were assessed with intramuscular EMG and arm movement was measured with a potentiometer. This study stated that when respiratory demand was increased, the diaphragm activity associated with arm movement decreased, because increased central respiratory drive may weaken the postural command reaching motor neurons. Hodges et al. (2000) investigated the mechanical output of the components of diaphragm activity. EMG was used to assess the costal diaphragm, erector spinae and abdominal muscles. Results showed that the diaphragm and transversus abdominis continuously contributed to respiration and postural control and the combined tonic and phasic activity provides a mechanism for the central neural system to coordinate respiration and control of the spine, causing increased IAP during limb movement. Hodges et al. (2000) studied the coordination between respiratory and postural functions of the diaphragm during repetitive upper limb movement. Intramuscular EMG for costal diaphragm and surface EMG for deltoid and erector spinae muscles, were used. It was concluded that during movement of the upper limb with increasing frequency, the peak acceleration of the upper limb correlated with diaphragm EMG amplitude, this supports the argument that diaphragm contraction is related to trunk control. Hodges et al. (1997) investigated the response of the diaphragm to the postural perturbation produced by rapid flexion of the shoulder to a visual stimulus in standing subjects. Results showed that EMG contraction of the diaphragm is 20ms prior to the onset of deltoid EMG, thereby suggesting the postural function of the diaphragm. Sinderby et al. (1992) studied the relationship between the roles of the diaphragm during arm exercise and trunk flexion in complete cervical cord injury patients. Activity of the diaphragm was measured with EMG. Results showed that the diaphragm acts both as a trunk extensor muscle and as a respiratory muscle. Additionally, during posture imbalance, the postural needs temporarily override the respiratory needs.

Hodges et al. (1997) studied the influence of respiratory function of the abdominal muscles on their reaction time in a postural task in healthy subjects. This study found that the latency between activation of the abdominal muscles and deltoid, measured by EMG, was not influenced by the respiratory cycle, during quiet breathing. Additionally, when respiratory activity of the abdominal muscles is increased (occurring in movements beginning at expiration, compared with inspiration), the EMG onset of transversus abdominis and internal oblique, relative to deltoid, was significantly earlier. Preliminary recordings from the diaphragm with intramuscular electrodes are consistent with its activation together with transversus abdominis in similar tasks to those used here. This study confirmed that one or more of the abdominal muscles contract before the agonist limb movement while standing as a preparatory activation of transversus abdominis and oblique internus. It is likely to be preprogrammed, because their onset occurred before any relevant afferent activity could initiate them.

Druz et al. (1982) studied EMG measurement of respiratory muscles in patients with severe COPD. The study found that all healthy subjects and four out of six COPD patients showed increases in EMG activity of the diaphragm during standing and erect sitting, compared to the other two COPD patients. In two out of six COPD patients EMG activity of the diaphragm did not increase in the erect postures; this reflex, which normally compensates for reduced diaphragmatic efficiency, is not working.

Uga et al. (2010) and Uga et al. (2010) investigated the intramuscular EMG activity of the diaphragm and trunk muscles in respectively two and four awake cats during voluntary movements. Findings included that during resting and normal walking alternately repeated active and inactive EMG phases were observed in the diaphragm, which is its respiratory activity. In contrast, during standing up (bipedal position, in which trunk muscles were activated) the diaphragm EMG became larger, longer and more irregular, considering that this is the postural activity of the diaphragm. Additionally, findings in the four cats included that after initiation of standing up there was more diaphragm activity, which occurred after the onset of trunk muscle activity. Further, during rotation movements an asymmetrical EMG pattern was shown in left and right diaphragmatic activities, with higher intensity than during rest. Finally, during reaching movements diaphragmatic activity occurred prior to, or simultaneously with the onset of trunk muscle activity.

4.3.1.2 Ultrasound (US)

Following studies (n= 6) examined the role of the diaphragm in core stability with US.

Hellyer et al. (2017) measured diaphragm thickness in 24 healthy subjects via B-mode ultrasound imaging in three different positions (supine, seated unsupported, and standing). In each position the diaphragm thickness was measured 3 times at maximal inspiration (total lung capacity) and at end-tidal expiratory lung volume. Results showed that in erect positions the absolute diaphragm thicknesses were greater than in the supine position. This study provides further framework for US as a clinical assessment tool of the diaphragm during functional postures and tasks.

Terada et al. (2016) examined diaphragm contractility in 27 individuals with chronic ankle instability (CAI) and 28 healthy controls. Diaphragmatic movement and thickness of right and left hemidiaphragm were measured with US at the end of resting in- and expiration. The main result is that patients with CAI had a smaller degree of left hemidiaphragm contractility compared with the control group. Consequently, this may be an illustration of diaphragm dysfunction and altered strategies produced by the central neural system to control neuromuscular function in individuals with CAI.

Priori et al. (2013) studied whether varying body positions from seated to supine would influence ribcage asynchrony by changing the configuration of the respiratory muscles. Twenty-three severe COPD patients were compared with 12 healthy controls. Changes in the diaphragm zone of insertion were measured with US. Results showed that the zone of insertion of the diaphragm in healthy subjects was not significantly different in the two postures. Furthermore, diaphragmatic displacement in COPD patients was greater seated compared with healthy controls. However, diaphragmatic displacement in the supine position was similar in both groups.

Uchida et al. (2010) assessed the effect of compression on the posterior surface of the thorax caused by a pillow used to create different postural conditions on respiratory function. The distance moved by the diaphragm was measured by an US imaging device. Measurements took place in the following positions: First, supine, half lateral with a pillow supporting the posterior of the thorax; Second, supine, half lateral with pillows supporting the shoulder girdle and the pelvic band. The main results were that in the first compared to the second posture, distance moved by the diaphragm was lower. It could be concluded that, there was less ventilation in the first posture. Therefore, the movement of the diaphragm was reduced due to an expanded state caused by an increase in residual air in the lungs.

O'Sullivan et al. (2002) investigated the motor control strategies of subjects with sacroiliac joint (SIJ) pain and its resultant effect on breathing pattern. Thirteen subjects with a clinical diagnosis of SIJ pain were compared with 13 matched control subjects. Movement of the diaphragm was recorded with US in three conditions: rest, active straight leg raise (ASLR) and ASLR with manual pelvic compression. At the same time, respiratory patterns were examined by spirometry and subsequently minute ventilation was calculated. Main results were that patients with SIJ pain have increased minute ventilation and decreased diaphragmatic excursion during ASLR. Moreover, when pelvic compression was given during ASLR, the two groups homogenized. Thus, Patients with SIJ pain have altered breathing pattern and altered kinematics of the diaphragm and pelvic floor by carry out a postural task.

Hodges et al. (1997) measured dynamic changes in the length of the diaphragm with US during a postural task produced by rapid flexion of the shoulder. This revealed that the diaphragm firstly shortened and then lengthened progressively during the increase in transdiaphragmatic pressure.

4.3.1.3 Magnetic resonance imaging (MRI)

Following studies (n= 5) examined the role of the diaphragm in core stability with MRI.

Vostatek et al. (2013) presented a postural analysis of the diaphragm function using MRI to identify changes in diaphragm motion and shape when postural demands on the body were increased.

Seventeen chronic low back pain patients with structural spine disorders and sixteen controls were compared. MRI of the diaphragm was performed during supine lying and supine lying with hip flexion against load. The main findings were that the pathological group had increased respiratory frequency, compared to the control group. Furthermore, controls had three times bigger diaphragm excursion in the lying position and six and a half times bigger diaphragm excursion in lying with load. Thus, the postural moves of the diaphragm in the control group were larger. In addition, 46.7% in situation 1 and 46% in situation 2 of the controls could maintain harmonicity of the diaphragm (able to keep control), in contrast to 29.7% and 25.5% respectively in situation 1 and 2 in the pathological group.

Kolar et al. (2012) and Kolar et al. (2010) both used limb movement as postural task. Kolar et al. (2012) examined the diaphragm excursions and inspiratory positions during normal tidal breathing and a postural task in 18 patients with chronic low back pain and 29 healthy volunteers. MRI was used to measure diaphragm excursion. Results in the patient group showed smaller diaphragm excursions and higher diaphragmatic position during isometric contractions of upper and lower extremities and during tidal breathing; maximal changes were found in costal and middle points of the diaphragm. This supports that the compromised function of the diaphragm in patients with low back pain could play an important role in postural stability. Kolar et al. (2010) described diaphragmatic behavior during postural limb activities and the ventilatory and stabilizing functions of the diaphragm in 30 healthy controls. Diaphragm excursion was measured with MRI and ventilation with spirometry. Results showed that diaphragmatic excursion was increased during upper and mostly during lower body activity, compared with tidal breathing. Nevertheless, there was a lower expiratory diaphragm position in lower extremity activity, when compared with tidal breathing. Furthermore, significantly lower values of tidal volume compared with diaphragm excursion were found in the lower extremity conditions. In conclusion, this comparison between percent change of diaphragm excursion and tidal volumes might contribute to the concept of the postural function in addition of the respiratory function of the diaphragm.

Kolar et al. (2009) analyzed the diaphragm movement with MRI in 16 healthy subjects. These measurements were taken under two conditions, firstly during tidal breathing and secondly by holding breathe at the end of expiratory tidal breathing, while performing an exercise sequence. Results showed diaphragm movement during voluntary breath holding, not only due to pressure changes but also due to active contraction. This supports that the phrenic nerve’s motor-neuron activity is organized in such a way that the diaphragm assists more than just respiration.

Takazakura et al. (2004) determined the postural difference of diaphragmatic motion between seated and supine positions with MRI in 10 healthy men. The main finding of this study was that diaphragmatic excursions in supine position were significantly greater than those in seated position, especially in the posterior portion.

4.3.2 Indirect methods

4.3.2.1 Pressures to evaluate IAP

Following studies (n= 17) examined the role of the diaphragm in core stability by measuring esophageal (Poes), gastric pressure (Pga), transdiaphragmatic pressure (Pdi= Poes-Pga) or intra-rectal pressure, to shed light on the IAP.

Kawabata et al (2014), Kawabata et al (2010) and Hagins et al (2004) all examined the IAP during a lifting task. Kawabata et al. (2014) studied the change in peak rate of IAP during dynamic load lifting. Following measurements were taken: hip joint angle and IAP measured by intra-rectal pressure transducer. Results showed no effect of the lifting load on the time of occurrence of IAP. Additionally, as lifting load increased, so did the time between lifting motion onset and IAP onset. Kawabata et al. (2010) examined whether spontaneous breath volume and IAP altered with increased isometric lifting effort, and to compare the effect of different abdominal muscles strengths on these parameters. This was measured in 10 healthy judo athletes and 11 healthy men. Maximal IAP was measured with an intra-rectal pressure transducer during vasalva maneuver and trunk muscle strength was measured with a dynamometer. Results showed higher maximal IAP and stronger trunk flexor muscles during the vasalva maneuver in trained athletes compared to controls. However, there was significantly less increase in %max IAP for the trained athlete group compared to the control group. Thus, IAP development is coupled with increased lifting effort and strong abdominal muscles can modify IAP development during lifting. Hagins et al. (2004) examined the effect of breath control on magnitude and timing of IAP during dynamic lifting, by using a microtip pressure transducer in the stomach (Pga), proving a significant effect of breath control and load, but not of posture on IAP. The inhalation form of breath control produced significantly greater peak IAP than all other forms of breath control.

Whüthrich et al. (2013) investigated whether postural demand placed upon the diaphragm during running could augment the development of diaphragm fatigue. This was tested in 11 runners and 11 cyclists. Used measurement tools were Poes and Pga to measure twitch Pdi in response to phrenic nerve stimulation. Twitch Pdi was more reduced after 15 time trials, which were more intense, than after 30 time trials, this was similar for runners and cyclists. In conclusion, the level of inspiratory muscle fatigue is independent of the exercise modality and related more to exercise intensity and the associated respiratory muscle work. Perhaps, postural demand placed upon the diaphragm during running resulted in a larger contribution of diaphragmatic fatigue to total inspiratory muscle fatigue compared to cycling which did not lead to greater fatigue resistance during volitional hyperpnoea in runners compared to cyclists.

Janssens et al. (2013) studied whether individuals with low back pain exhibit greater diaphragm fatigability compared to healthy controls. Twitch Pdi was measured with Poes and Pga. Results showed a significantly decreased potentiated twitch Pdi in individuals with low back pain after inspiratory muscle loading compared to healthy controls. Furthermore, diaphragm fatigue was present in 80% (after 20 minutes) and 70% (after 45 minutes) of the individuals with low back pain after inspiratory muscle loading, whereas, only respectively 40% and 30% in healthy controls.

Hart et al. (2005) assessed the effect of custom girdles in patients with spinal cord injury, with both truncal and abdominal support, on the sensation of respiratory effort, pulmonary function, diaphragmatic load and diaphragmatic strength in patients with spinal cord injury during spontaneous breathing while in a seated position. Poes and Pga were used to measure Pdi, which increased due the girdle.

Bitnar et al. (2016), Beales et al (2010) and Gandevia et al. (1990) all examined the IAP during ASLR. Bitnar et al. (2016) determined the relation between posturally increased IAP and lower/upper esophageal sphincter pressure changes in patients with gastro-esophageal reflux disease, during bilateral ASLR. Pressure changes in lower and upper esophageal sphincter were measured by high-resolution manometry. Results showed a significant increase in both lower and upper esophageal sphincter pressure. Furthermore, patients with initially higher pressure in lower and upper esophageal sphincter exhibited a greater pressure increase during ASLR. Beales et al. (2010) investigated how pain-free subjects coordinate motor control during an ASLR when this task was complicated by the addition of a respiratory challenge. IAP and intra-thoracic pressure were measured with a nasogastric catheter. Results showed greater IAP baseline shift (pressure change related to the physical load of an ASLR) when lifting the leg during ASLR and inspiratory resistance. This was associated with the increase of motor activity. Gandevia et al. (1990) measured Pdi with a multi-lumen Poes and Pga catheter. Results showed an average change in Pdi while relaxation, during bilateral phrenic nerve stimuli. Also, the peak voluntary Pdi was about 30% less for inspiratory than for expulsive maneuvers (in this maneuver, the diaphragm and abdominal muscles act as synergists to elevate pressure in the abdomen, which was attained in this study by supine lying with double ASLR and elevated trunk). During transcranial activation, an increment in Pga occurred during maximal voluntary expulsive efforts. Thus, the abdominal muscles fail to generate full contractile force. During motor cortical stimulation, a small reduction of Poes was shown during weak inspiratory efforts.

Hodges et al (2005) and Shirley et al (2003) both examined the relation between IAP and spinal stiffness. Hodges et al. (2005) determined whether spinal stiffness increased when IAP increased (by tetanic unilateral or bilateral stimulation of the phrenic nerves) without concurrent activity of the abdominal and back extensor muscles. Poes and Pga were measured with a thin-film strain gauge pressure transducer. Furthermore, erector spinae and abdominal muscle activity was measured with EMG and lumbar postero-anterior stiffness via analysis of the applied force on, and linear displacement of L2 end L4. Results showed that with tetanic stimulation of the diaphragm, the IAP increased 27-61% and the spinal stiffness increased 8-31%. Furthermore, spinal stiffness increased 16% when erector spinae EMG activity increased. Thus, modulation of IAP provides an additional mechanism for the central nervous system to control spinal stability during functional activities and may simplify this control by providing non-direction-specific increase in stiffness. Shirley et al. (2003) investigated whether stiffness is modulated in a cyclical manner with respiration and whether there is a relationship between stiffness and IAP or abdominal and paraspinal muscle activity. IAP was measured with Pga. Furthermore, erector spinae and abdominal muscle activity was measured with EMG, and lumbar postero-anterior stiffness was measured via analysis of the applied force on, and linear displacement of L2 end L4. Results showed an increased lumbar stiffness above base level of functional residual capacity in both respiratory efforts. Additionally, spinal stiffness was modulated by changes in trunk muscle activity and IAP by respiratory efforts. Consequently, the diaphragm may augment spinal stiffness via attachment of its crural fibers to the lumbar vertebrae.

Hodges et al. (2003) investigated the effect of transversus abdominis and diaphragm activity and increased IAP on intervertebral kinematics in eleven porcine lumbar spines. EMG electrodes were used to measured activity of transversus abdominis, IAP was measured with a Pga catheter and movement of the lumbar spine was measured with motion sensors attached to the L3 and L4 spinous processes. Results stated that elevated IAP and contractions of diaphragm and transversus abdominis provide a mechanical contribution to the control of spinal intervertebral stiffness.

Hodges et al (2001), Hodges et al (2000) and Hodges et al (1997) examined IAP during rapid limb movement. Hodges et al. (2001) recorded Pga with a pressure transducer to determine whether it changed in parallel with the changes in diaphragm and transversus abdominis EMG (4.3.1.1). Results showed that Pga was maintained at an elevated level during arm movement and the mean amplitude of this Pga increase across the period of arm movement was reduced when ventilation increased. Hodges et al. (2000) used Pga and Poes to measure IAP and intra-thoracic pressure, which increased due to rapid repetitive limb movement during breathing. This increase was maintained until the end of the task. Hodges et al. (1997) used Poes and Pga to measure Pdi, which increased with rapid arm flexion.

Sinderby et al (1992) and Druz et al (1982) both examine the IAP during trunk flexion. Sinderby et al. (1992) used Poes and Pga to measure IAP. Results showed increased mean Pga and declined mean Poes in trunk flexion compared with rest. Furthermore, at maximal trunk flexion Pga reached a plateau. Exercise indicated a decrease in both Poes and Pga. However, the decline in mean Poes was more pronounced during trunk flexion than during exercise. Druz et al. (1982) measured Poes, Pga and Pdi with a gastro-esophageal balloon catheter. Results showed that healthy subjects maintained Pdi in all 4 postures (supine, standing, erect sitting and forward leaning). Further, Pdi decreased in COPD patients during erect sitting and standing.

4.3.2.3 Inspiratory muscle strength

Following studies (n= 3) examined the role of the diaphragm in core stability with measurement of inspiratory muscle strength.

Segizbaeva et al. (2013) studied MIP in healthy subjects, measured from residual volume. There were lower results of MIP in supine compared to standing posture, as well in men as in women, but with no significant difference.

Griffiths et al. (2012) assessed the influence of the postural role of the trunk muscles upon pressure and flow generation capacity by measuring MIP, flows, and volumes in various seated postures relevant to rowing, which were: catch, sitting upright, finish. A portable handheld mouth pressure meter was used to measure MIP as a surrogate of inspiratory muscle strength. MIP tended to decrease with recumbency, but not significantly.

Jandt et al. (2011) evaluated the correlation between trunk control, inspiratory muscle strength and pulmonary function in 23 individuals who suffered stroke. MIP was measured with manovacuometry and trunk control with the trunk impairment scale. Results showed a consistent correlation between trunk impairment scale and MIP, but not significant (p= 0,054). However, because it is nearly significant, a greater sample size would probably show significance.

4.3.2.4 Inspection or palpation of breathing patterns

Following studies (n= 4) examined the role of the diaphragm in core stability by inspection or palpation of the breathing pattern by interpreting dominant abdominal excursion during breathing as diaphragmatic breathing.

Hagins et al. (2011) determined if, during a whole body-lifting task, individuals with low back pain breathe differently than age-matched controls. Patients used their preferred lift style to remove the crate from the floor to a platform. Results showed that individuals with low back pain performed the lifting task with more volume in their lungs than healthy peers, and that with increasing age, participants with low back pain increased inspired volume and participants without low back pain decreased inspired volume. In conclusion, this study provides the first evidence that natural breath control during a lifting task differs significantly in individuals with LBP, who had more inhaled lung volume, compared to age-matched and gender-matched healthy controls. These findings are consistent with the theoretical link between breath control, IAP, and core stabilizing function.

Roussel et al. (2009) evaluated the breathing patterns in 10 chronic low back pain patients and in 10 healthy subjects in different types of conditions: during rest (standing and supine, both while spontaneous breathing and deep breathing) and during motor control tests (bent knee fall out and active straight leg raise). Breathing patterns were evaluated by inspection and palpation. Following breathing patterns were defined: costo-diaphragmatic, considered as normal, and asynchronous breathing among which: paradoxical breathing, upper costal breathing, mixed breathing and breath holding. Furthermore, pressure changes were recorded with the pressure biofeedback unit, which monitored lumbopelvic movement. Results showed at rest no significant differences between the breathing patterns of patients compared with healthy subjects. However, during motor control tests patients with chronic low back pain showed more altered breathing patterns, compared to normal breathing. These results showed that altered breathing patterns are a consequence of postural disturbance in a subgroup of low back pain patients, compared to healthy subjects. Lastly, changes in breathing patterns were not related to pain severity but to motor control dysfunction.

Hamaoui et al. (2014) studied if displacement of the center of gravity following voluntary, high intensity sniff maneuvers is predominantly due to diaphragm contraction. Signals derived from the thoracic and abdominal sensor belts were used to detect changes in rib cage and abdominal circumference. Phrenic nerve stimulation was done to determine displacement of center of gravity following selective diaphragm contractions. Whereas, sniff maneuvers were done to ensure predominantly diaphragm contraction. Results showed that the abdominal peak had an outward direction (inspiratory) and the thoracic peak had an inward direction (expiratory).

Priori et al. (2013) used opto-electronic plethysmography to measure the phase shift between upper and lower rib cage and between upper ribcage and abdomen during quiet breathing in different body positions (seated to supine). This was investigated in 23 severe COPD patients and twelve healthy controls. Main findings in COPD patients were, asynchrony between upper and lower ribcage in seated posture but not in supine posture, and asynchrony between upper ribcage and abdomen in supine position but not in seated position. This study concluded that, in COPD patients, chest wall asynchronies are significantly influenced by body position.

4.3.2.6 Postural control measures during respiratory disturbance

Following studies (n= 6) examined the role of the diaphragm in core stability by postural control measures during respiratory disturbance.

Hamaoui et al (2014) studied the postural disturbances caused by isolated contractions of the diaphragm (unilateral and bilateral with phrenic nerve stimulation and sniff maneuvers) in seated posture as well as in standing posture. Therefore, following methods were used: a force plate to measure the center of gravity and EMG to assess the actual activity of the diaphragm. The main results were that in seated posture the center of gravity acceleration peak is directed forward, in contrast to the standing posture whereby the center of gravity acceleration peak is directed backward. Furthermore, unilateral phrenic stimulation resulted in an additional medial-lateral acceleration of center of gravity to the active side while standing, and to the non-active side while seated.

Janssens et al. (2014) investigated whether eight weeks of inspiratory muscle training affects proprioceptive use in 28 persons with low back pain during postural control. Centre of pressure displacement was measured during muscle vibration using a six-channel force-plate. Results showed that proprioceptive use during postural control was improved after inspiratory muscle training.

Janssens et al. (2010) determined postural stability and proprioceptive postural control strategies of 12 healthy subjects and 12 subjects with recurrent low back pain during acute inspiratory muscle loading (breathing against an inspiratory resistance). Postural stability was measured by center of pressure displacement on a force plate, and proprioceptive postural control strategies were examined by vibration of triceps surae muscle or lumbar paraspinal muscles while standing on a stable / unstable surface without vision. Results showed a larger sway after inspiratory muscle loading in healthy controls, because due to proprioceptive reweighting they tend to use a rigid postural control strategy over a more effective “multi-segmental” control strategy.

Almeida et al. (2013) compared balance in asthma patients, according to the severity of disease. Fifty participants with asthma were divided in two groups: A, with FEV1>74% and B, with FEV1<74% predicted. Static postural balance (stabilometry) was measured on a force platform while maintaining a static posture with the eyes open and legs hip-width apart for 30 seconds. In addition inspiratory muscle strength was measured using the computerized Collins Plus Pulmonary Function Testing Systems. Results showed a decreased MIP in group B compared to group A. Furthermore, maximal mediolateral velocity and mediolateral displacement were significantly greater in group B, compared to A. Conclusively, in adult individuals with asthma, pulmonary function is associated with balance control in the mediolateral direction.

Janssens et al. (2013) determined the specific proprioceptive use during postural control in 20 individuals with COPD and 20 healthy controls and assessed whether this was related to inspiratory muscle weakness. An electronic pressure transducer measured MIP. Results showed that COPD patients, especially those with low MIP, had decreased postural stability and adopted a less optimal proprioceptive use during postural control (greater reliance on ankle muscle proprioceptive input).

Smith et al. (2010) compared balance between 12 people with and 12 without COPD to determine if balance deteriorates when respiratory demand is increased by upper limb exercise. Centre of pressure displacement was measured with a force plate, and inclinometers were used to determine lumbar spine and hip motion. Results showed in COPD patients increased mediolateral center of pressure displacement and increased angular motion of the hip compared to healthy controls. Additionally, mediolateral center of pressure displacement was further increased in people with COPD following exercise, but unchanged in controls.

5. Discussion

The purpose of this study was to summarize the measurement tools to assess the core stabilizing function of the diaphragm. These measurement tools could be divided in two major groups namely direct and indirect methods to assess the core stabilizing function of the diaphragm. Firstly, the direct methods involved 12 studies using EMG, five studies using US and five studies using MRI. Secondly, the indirect methods involved 17 studies measuring IAP, seven studies measuring MIP, four studies using inspection or palpation of breathing patterns and six studies using postural control measures during respiratory disturbance. Thus, all of these methods, or a combination of these, was used to evaluate the postural role of the diaphragm in different populations.

EVALUATION OF DIAPRHAGM FUNCTION

EMG measurements provide direct information about muscle activation. An esophageal catheter or surface electrodes could be used for EMG measurements of the diaphragm. This latter is a non-invasive method, which is more applicable in practice. However, it does not provide selective recordings, as it represents activity of the diaphragm as well as other trunk muscles such as intercostal muscles, serrates anterior, external oblique abdominal muscles etc. (P. W. Hodges, Eriksson, Shirley, & Gandevia, 2005). On the other hand, an esophageal catheter measures the diaphragm more precisely, but it’s an invasive method, which makes it harder to use in practice.

Measurements with US can accurately measure thickening and downward displacement of the diaphragm (to be interpreted as diaphragm activation), but as with any other diagnostic technique, diaphragm US is operator dependent. However, with practice and adherence to the criteria to make a proper image, this measurement of diaphragm thickening should prove to be reproducible (Cohn, Benditt, Eveloff, & McCool, 1997). Advantages are that real time US of the diaphragm is a simple, inexpensive, portable imaging technique, but disadvantages are that measurements of diaphragm thickness could be highly variable depending on which intercostal space was chosen (Boon et al., 2013), and body mass index (BMI) > 30 kg/m^2 could create a risk of inability to take clear ultrasound imaging pictures (Kantarci et al., 2004).

MRI measurements give a detailed and complete interpretation of the excursion of the diaphragm (more excursion to be interpreted as more activation of the diaphragm). It was proven that MRI could be used to reliably record diaphragm movements (Gierada et al., 1997). However, MRI measurements are expensive and it’s a large stationary device, which makes it difficult to use in a clinical practice of a physiotherapist.

Several studies combined EMG with pressures to measure IAP, to map the postural activity of the diaphragm and other trunk muscles e.g., transversus abdominis. An increase in IAP means an increase in spinal stiffness, which thereby increases the trunk control (P. W. Hodges et al., 2005). The advantage of EMG measurements of several trunk muscles, together with IAP changes, is that the researcher can examine which specific muscle (for example diaphragm versus trunk muscles) actually contributes to the postural stability during a postural task.

MIP measures inspiratory pressure, which is an indicator for the inspiratory muscle force. Therefore, MIP can be linked to diaphragm force, which is an inspiratory muscle. This measurement is inexpensive, portable, and easy to use for diagnosis as well as in therapy. A disadvantage is that MIP results give an overall interpretation of inspiratory muscle force, so it's not precisely shown which exact muscle contributes to the measured inspiratory muscle strength. So, it is not sure that the role of the diaphragm is examined.

Inspection or palpation is easy to use in clinical practice for evaluation of the breathing pattern. Assessment of abdominal movement could be used to confirm whether the breathing is diaphragmatic or not. However, it's a subjective way to analyze contraction of the diaphragm in postural stability tasks. In low back pain patients, there is evidence that the inter-observer reliability of the assessment of breathing pattern is fair to moderate (ICC: 0.4-0.6 / 1) (N. A. Roussel, Nijs, Truijen, Smeuninx, & Stassijns, 2007).

CORE STABILITY TASKS

Different studies used limb movement to produce a postural task and measure diaphragm activation continuously during this task, for example by EMG (Sinderby, Ingvarsson, Sullivan, Wickstrom, & Lindstrom, 1992), Poes, Pga and Pdi (P. W. Hodges et al., 1997), US (P. W. Hodges et al., 1997) or MRI (Kolar et al., 2010).

Since EMG is only connected to the patient with wires or even wireless, it is the most versatile measurement tool. Because of this it can measure the diaphragm during postural tasks in many positions (sit, supine as well as standing) and movements (exercises, trunk flexion, lifting tasks etc.).

MRI is the least flexible method to measure the diaphragm; only postural tasks in supine lying can be done, because the patient has to lie in the vast device. Exceptionally, there is a possibility to measure in sitting position with an altered MRI device (Takazakura, Takahashi, Nitta, & Murata, 2004). Greater excursion of the diaphragm, measured with MRI, during upper and lower body activity compared to a breathing task can shed light on the amount of core stabilizing function of the diaphragm.

US measurements are most precise in postural tasks without movement of the trunk (e.g. supine lying, ASLR), because the probe is handled manually. Movement of the trunk might make the measurement of the diaphragm less accurate.

IAP measurement (Poes, Pga and Pdi) is the most invasive, which makes it less applicable in practice. However, it can be combined with every postural task, because the patient is only connected with wires to the device. During limb movement (postural task), it's stated that the diaphragm should continuously contribute to trunk control, together with transversus abdominis, causing increased IAP (P. W. Hodges & Gandevia, 2000). The mechanism behind this increased IAP is the following: Initially shortening of the diaphragm (increased EMG activation), but then lengthening as IAP increased. This suggests an eccentric contraction of the diaphragm following contraction of transversus abdominis and other trunk muscles e.g., pelvic floor. Thus, the diaphragm has an anticipatory function when a postural task is performed, it's even indicated that the diaphragm should contract 20ms prior to contraction of limb muscles (P. W. Hodges et al., 1997). When this is not the case, for example during slower or decreased IAP generation during limb movement, a reduced role of the diaphragm in trunk control can be concluded.

Some studies used increased respiratory demand to investigate the role of the diaphragm associated with core stability. When decreased diaphragm activity is observed as a result of respiratory demand during a postural task, it could be concluded that the diaphragm actually contributes to postural stability (P. W. Hodges, Heijnen, & Gandevia, 2001).

PATIENT POPULATIONS

The following studies examined patients with respiratory disorders, COPD and asthma, to evaluate the role of the diaphragm in trunk control. Because COPD patients show an increased risk of falls, they are investigated for postural balance (Roig, Eng, Road, & Reid, 2009). Druz et al. (1982) stated that in severe COPD patients, EMG activity in erect postures was not increased. Conclusively, this reflex that normally compensates for reduced diaphragmatic efficiency is not working. Priori et al. (2013), using US, showed that in erect sitting COPD patients have larger excursions of the diaphragm compared to healthy controls. Janssens et al. (2013) showed that COPD patients, especially those with low MIP, had decreased postural stability. Smith et al. (2010) found that in COPD patients, balance is compromised, especially in mediolateral direction (controlled by hips and trunk). Due to an inadequate contribution of the trunk to balance, even more after exercise. These results are also found in asthma patients when FEV1 < 74% predicted (Almeida et al., 2013). It can be concluded that in patients with increased respiratory needs, like in COPD and asthma, the postural contribution of the diaphragm is decreased because of this. All these results come from patients with respiratory disturbance; therefore the effect of decreased diaphragm function on postural balance is indirectly measured. This is a manner to evaluate the role of the diaphragm in postural control.

In patients with sacroiliac joint pain diaphragmatic excursion, measured with US, decreased during ASLR compared to healthy controls. However, when pelvic compression was given this result homogenized for the two groups (O'Sullivan et al., 2002). This indicates that instability of the pelvis affects contractility of the diaphragm. Possibly, when stability is restored by compression, the diaphragm had to contribute less to the postural control and was able to restore its respiratory function. Similar results were found in patients with low back pain. Vostatek et al. (2013) measured the diaphragm with MRI. Compared with healthy controls, the excursion of the diaphragm was three times smaller in the lying position and six and a half times smaller in ASLR with load. When a load was applied to the lower limbs, the pathological subjects were mostly not able to maintain the respiratory diaphragm function, which was lowered significantly (Vostatek, Novak, Rychnovsky, & Rychnovska, 2013). Kolar et al. (2012) also showed smaller diaphragm excursions during limb movement as well as a higher diaphragmatic position (Kolar et al., 2012). Furthermore, Janssens et al. (2013) showed a decreased twitch Pdi and an increased fatigability of the diaphragm in patients with low back pain after inspiratory muscle loading, compared to healthy controls (Janssens, Brumagne, McConnell, Hermans, et al., 2013). In addition, there is evidence that natural breath control during a lifting task is different in patients with low back pain, who had more inhaled lung volume compared to gender-matched healthy controls (Hagins & Lamberg, 2011). Possibly, because these patients have decreased stability of the spine, the inspired volume is increased to reassure the IAP during a lifting task, which provides stability of the spine. Moreover, it's stated that during motor control tests, patients with chronic low back pain showed more altered breathing patterns, compared to normal breathing (N. Roussel et al., 2009). This may give therapists the opportunity to evaluate the diaphragm in a subgroup of patients with low back pain, by observing breathing pattern during a postural task. Lastly, it's found that proprioceptive use during postural control was improved after inspiratory muscle training in patients with low back pain (Janssens et al., 2015). This may provide a method of clinical rehabilitation for this patient population.

Jandt et al. (2011) examined patients with stroke, of whom is known that they have impaired core stability. By measuring the MIP in this specific patient group, the role of the diaphragm in core stability could be assessed. A correlation between trunk impairment scale and MIP was found, so indirectly it could be concluded that activity of the diaphragm, which is necessary for MIP, contributes to trunk stability. Subsequently, increasing the MIP may contribute to improving the trunk stability, which might provide an interesting addition to the rehabilitation plan.

In patients with tetraplegia it's demonstrated that postural needs temporarily override respiratory needs during posture imbalance, e.g., by arm exercise or trunk flexion (Sinderby et al., 1992). A possible explanation for this phenomenon is that patients with tetraplegia don't have many other functional trunk muscles to preserve postural control, so when these patients are threatened to lose postural control by flexing the trunk or moving the arms, the postural function of the diaphragm override its respiratory function for that instant. Hart et al. (2005) investigated a possible opportunity to increase IAP by applying a custom girdle in patients with spinal cord injury, which could simplify the postural task of the diaphragm. However, the girdle decreases dynamic abdominal compliance, which could lead to additive atrophy.

ANIMAL STUDIES

Studying animals is another method to examine the role of the diaphragm in trunk control. By doing so, it is possible to perform more invasive procedures compared to humans. E.g. implanting electrodes in the muscles, attachment of stimulation electrodes to phrenic nerve, insertion of pins in the lumbar vertebrae to invoke movement of the vertebrae etc. These invasive procedures provide more correct measurement results (Uga, Niwa, Ochiai, & Sasaki, 2010a, 2010b) and (P. Hodges et al., 2003). The results in these animal studies are similar to those found in studies with human subjects, but it's hard to transfer these results from cats and pigs directly to a human population.

LIMITATIONS

A limitation of this review includes that there were no excluded studies based on quality, because the review focused on the different manners to assess the postural function diaphragm with associated measurement tools. Hereby, there could be some low-quality articles included. There are also several strengths to this study. First, the research strategy was extended, so there was a minimal possibility of missing out on important articles. Second, this study is the first to summarize information about measurement tools, which are used to register the role of the diaphragm in the core-stabilizing task. Third, two independent reviewers carried out the research strategy and the quality assessment. However, the data-extraction was performed in consultation between the two reviewers.

CLINICAL MESSAGE

This review could be useful in the clinical practice; on the one hand, it stimulates therapists to recognize the importance of the diaphragm in clinical investigation, to use it for diagnosis and rehabilitation. On the other hand, it gives researchers and therapists an overview of the different manners and (dis)advantages to evaluate the postural contribution of the diaphragm. Consequently, therapists and researchers could use a proper measurement tool, adjusted to the setting of interest. For example, when the infrastructure is available and an overall view is wanted, MRI is the most precise when the postural task is in supine. In addition, US is also a precise measurement tool when the postural task is performed with a rigid thorax. However, when there is suspicion of a stability problem caused by a disturbed IAP, e.g. in patients with low back pain, it's indicated to evaluate the IAP in a specified setting. Furthermore, when a specific activation or strength related problem of the diaphragm is expected, it's best to investigate the patient with EMG. At last, methods indicated for a quick overall check, which can be easily performed in practice are MIP measurements or inspection and palpation of breathing patterns.

Following pathologies are already explored in this domain: COPD, asthma, low back pain, ankle instability, spinal cord injury, sacro-iliac joint pain and stroke. Probably the diaphragm plays an important, yet unknown role in many more pathologies, which could be investigated in further research.

6. Conclusion

The diaphragm contributes to trunk control via IAP and stiffening of the spine while performing a postural task. There has been done a lot of research regarding the role of the diaphragm in postural control, using many different measurement tools, in healthy populations as well as in patient populations. Used measurement tools are EMG and IAP, which are more flexible because all postural tasks can easily be performed while measuring. Furthermore MRI and US are more rigid because postural tasks, which can be performed while measuring, are limited. Other useful measurement tools are MIP, inspection or palpation of breathing patterns and postural control measures during respiratory disturbance. Several postural tasks, which could be used to examine the postural contribution of the diaphragm are unilateral or bilateral ASLR eventually with resistance, sit or stance compared to supine, trunk flexion, limb movement (e.g. rapid shoulder flexion), lifting task, standing on unstable surface, knee bend fall out etc. Additionally, assessment of patient populations (e.g., COPD), compared to healthy controls is also a method to (indirectly) evaluate the role of the diaphragm in core stability.

With this review, therapists and researchers have an overview concerning these measurement tools, which makes it easy to choose a measurement tool in practice or research. Still, there are some gaps to perform further research on, e.g., US has already been studied in a couple of patient populations, but there is a lack of systematic data and evidence about reliability and validity in healthy subjects while performing a postural task.

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8. Attachments

TABLE 1: Overview of used search terms, combinations and hits in PubMed and Web of Science.

	Terms	December 2016	June 2017
#1	Diaphragm [MESH]	19 299	31 799
#2	Diaphragm	47 263	48 000
#3	Core stability	10 359	11 068
#4	Postural balance [MESH]	17 715	18 329
#5	Postural balance	18 118	20 493
#6	Stability	356 313	370 395
#7	Postural control	14 183	14 701
#8	Trunk control	23 895	24 526
#9	Trunk stability	2 126	2 230
#10	Postural stability	4 341	4 542
#11	Postural function	27 255	27 980
#12	Respiratory muscles [MESH]	24 566	24 756
#13	Respiratory muscles	32 342	32 667
#1 AND #3	Diaphragm [MESH] AND Core stability	2	2
#1 AND #4	Diaphragm [MESH] AND Postural balance [MESH]	8	8
#1 AND #5	Diaphragm [MESH] AND Postural balance	9	9
#1 AND #6	Diaphragm [MESH] AND Stability	96	98
#1 AND #7	Diaphragm [MESH] AND postural control	19	19
#1 AND #8	Diaphragm [MESH] AND trunk control	153	154
#1 AND #9	Diaphragm [MESH] AND trunk stability	13	13
#1 AND #10	Diaphragm [MESH] AND postural stability	5	5
#1 AND #11	Diaphragm [MESH] AND postural function	66	66
#2 AND #3	Diaphragm AND Core stability	5	5
#2 AND #4	Diaphragm AND postural balance	20	21
#2 AND #5	Diaphragm AND postural balance [MESH]	17	17
#2 AND #6	Diaphragm AND Stability	231	233
#2 AND #7	Diaphragm AND postural control	33	34
#2 AND #8	Diaphragm AND trunk control	262	264
#2 AND #9	Diaphragm AND trunk stability	27	28
#2 AND #10	Diaphragm AND postural stability	8	8
#2 AND #11	Diaphragm AND postural function	121	122

#12 AND #3	Respiratory muscles [MESH] AND Core stability	2	2
#12 AND #4	Respiratory muscles [MESH] AND Postural balance [MESH]	15	15
#12 AND #5	Respiratory muscles [MESH] AND Postural balance	19	19
#12 AND #6	Respiratory muscles [MESH] AND Stability	106	108
#12 AND #7	Respiratory muscles [MESH] AND postural control	39	39
#12 AND #8	Respiratory muscles [MESH] AND trunk control	205	207
#12 AND #9	Respiratory muscles [MESH] AND trunk stability	18	18
#12 AND #10	Respiratory muscles [MESH] AND postural stability	9	9
#12 AND #11	Respiratory muscles [MESH] AND postural function	121	121
#13 AND #3	Respiratory muscles AND Core stability	4	5
#13 AND #4	Respiratory muscles AND postural balance	36	36
#13 AND #5	Respiratory muscles AND postural balance [MESH]	29	29
#13 AND #6	Respiratory muscles AND Stability	206	212
#13 AND #7	Respiratory muscles AND postural control	79	80
#13 AND #8	Respiratory muscles AND trunk control	267	270
#13 AND #9	Respiratory muscles AND trunk stability	29	30
#13 AND #10	Respiratory muscles AND postural stability	15	15
#13 AND #11	Respiratory muscles AND postural function	121	213
PubMed	(Respiratory muscles [MESH Terms] OR diaphragm[MeSH Terms]) AND ((postural function) OR (trunk stability) OR (trunk control))	345	347
PubMed	Author: Smith MD AND Hodges PW	11	11
WOS	(Respiratory muscles [MESH Terms] OR diaphragm[MeSH Terms]) AND ((postural function) OR (trunk stability) OR (trunk control))	194	202
WOS	Author: Smith MD AND Hodges PW	11	11

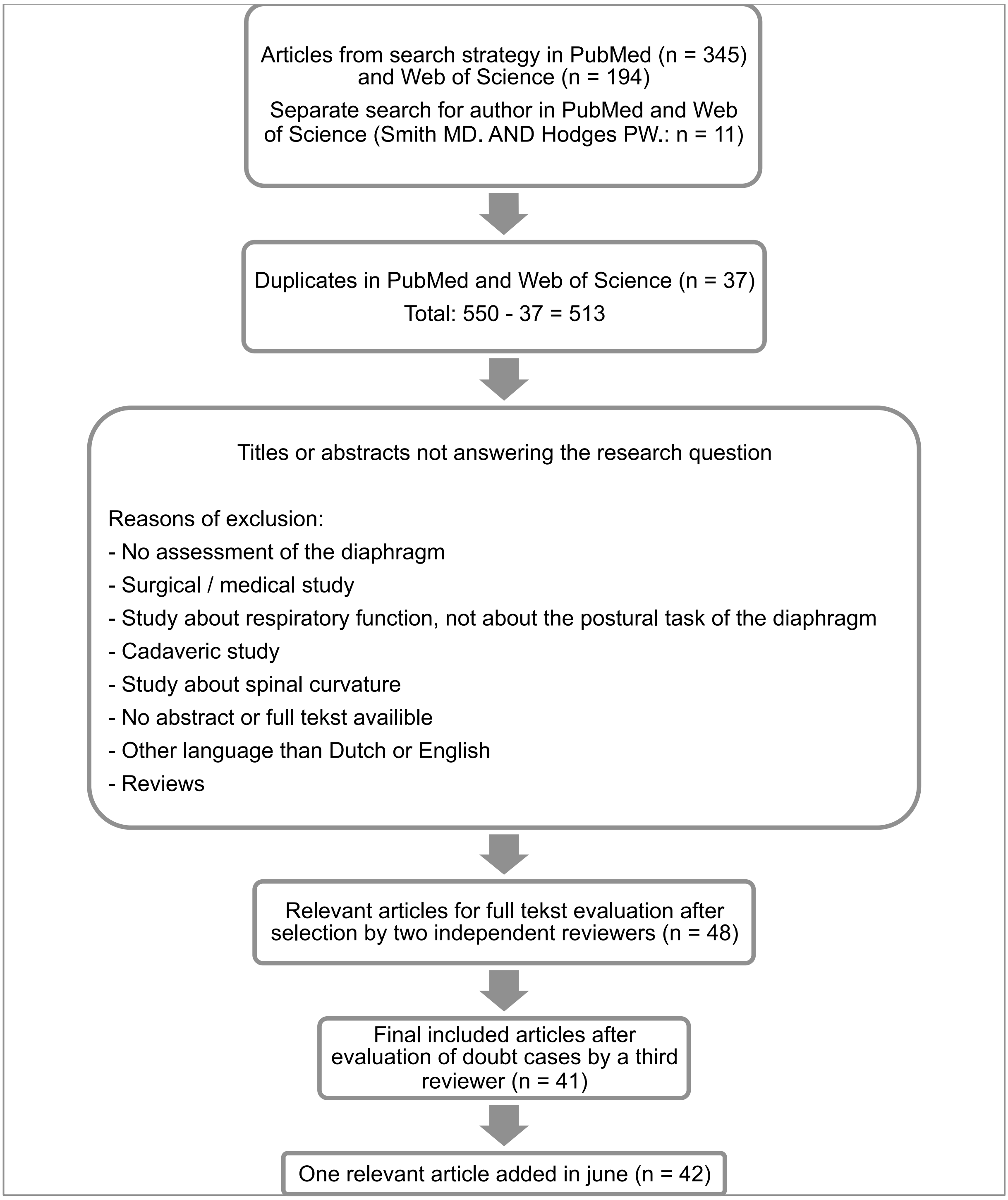

FIGURE 1: Flowchart of search strategy

TABLE 2A: Overview excluded studies and reason of exclusion PubMed

Source	Title	Reason of exclusion
Adams L. et al. (1989)	Synchronization Of Motor Unit Firing During Different Respiratory And Postural Tasks In Human Sternocleidomastoid Muscle.	No assessment of the diaphragm
Agostoni E. et al. (1985)	Reflex Partitioning Of Inputs From Stretch Receptors Of Bronchi And Thoracic Trachea.	No assessment of the diaphragm
Aliverti A. et al. (2002)	Respiratory Muscle Dynamics And Control During Exercise With Externally Imposed Expiratory Flow Limitation.	About respiratory function of the diaphragm
Aliverti A. et al. (2011)	Effects Of Propofol Anaesthesia On Thoraco-Abdominal Volume Variations During Spontaneous Breathing And Mechanical Ventilation.	Medical study
Allen SC. et al. (2006)	The Tendency To Altered Perception Of Airflow Resistance In Aged Subjects Might Be Due Mainly To A Reduction In Diaphragmatic Proprioception.	About respiratory function of the diaphragm
Alonso Calderon JL. (2006)	Morpho-Functional Study Of Electrostimulated Latissimus Dorsi Muscle Flap For Diaphragm Substitution.	Surgical study / other language than Dutch or English
Alonso JF. et al. (2011)	Coordination Of Respiratory Muscles Assessed By Means Of Nonlinear Forecasting Of Demodulated Myographic Signals.	About respiratory function of the diaphragm
Andrada L. et al. (2001)	Functional Respiratory Evaluation In Patients With High Traumatic Spinal Injury.	About respiratory function of the diaphragm / other language than Dutch or English
Arita H. et al. (1983)	Multiplicity Of Functional Behavior Of Human Intercostal Muscles.	No assessment of the diaphragm
Arnold JS. et al. (1987)	Length-Tension Relationship Of Abdominal Expiratory Muscles: Effect Of Emphysema.	No assessment of the diaphragm
Aronson RM. et al. (1991)	Upper Airway Muscle Activity And The Thoracic Volume Dependence Of Upper Airway Resistance.	About respiratory function of the diaphragm
Arshian M. et al. (2007)	Consequences Of Postural Changes And Removal Of Vestibular Inputs On The Movement Of Air In And Out Of The Lungs Of Conscious Felines.	No assessment of the diaphragm
Austin JH. et al. (1992)	Enhanced Respiratory Muscular Function In Normal Adults After Lessons In Proprioceptive Musculoskeletal Education Without Exercises.	About respiratory function of the diaphragm
Avni A. et al. (1983)	The Peritoneal Reaction To The Translocated Copper Intrauterine Device In Women And Female Rats.	No assessment of the diaphragm
Barach AL. (1974)	Chronic Obstructive Lung Disease: Postural Relief Of Dyspnea.	No assessment of the diaphragm
Barash A. et al. (1990)	Development Of Human Embryos In The Presence Of A Copper Intrauterine Device.	No assessment of the diaphragm
Barba E. et al. (2015)	Abdominothoracic Mechanisms Of Functional Abdominal Distension And Correction By Biofeedback.	No assessment of the diaphragm
Barbin IC. et al. (2016)	Diaphragm degeneration and cardiac structure in mdx mouse: potential clinical implications for Duchenne muscular dystrophy.	About respiratory function of the diaphragm
Barbosa PR. et al. (2003)	Reduction Of Electromyographic Noise In The Signal-Averaged Electrocardiogram By Spectral Decomposition.	No assessment of the diaphragm
Bastianelli C. et al. (1998)	Risk Factors For Ectopic Pregnancy. Case-Control Study.	No assessment of the diaphragm / Other language than Dutch or English
Bellemare F. et al. (2007)	Sex Differences In Thoracic Adaptation To Pulmonary Hyperinflation In Cystic Fibrosis.	About respiratory function of the diaphragm
Ben-Ari A. et al. (2009)	Ultrasound-Guided Paravertebral Block Using An Intercostal Approach.	Surgical study
Benoist M.	Reviewer's Comments Concerning "Altered Breathing Patterns During Lumbopelvic Motor Control Tests In Chronic Low Back Pain: A Case-Control Study" (J. Nijs Et Al., ESJO-D-08-00264 R2).	Review
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Billig I. et al. (2000)	Definition Of Neuronal Circuitry Controlling The Activity Of Phrenic And Abdominal Motoneurons In The Ferret Using Recombinant Strains Of Pseudorabies Virus.	Medical study
Binks AP. et al. (2001)	Oscillation Of The Lung By Chest-Wall Vibration.	No assessment of the diaphragm
Bishop B. (1963)	Reflex Control Of The Abdominal Muscles During Positive Pressure Breathing. Techn Docum Rep Amrl-Tdr-63-103 (I).	About respiratory function of the diaphragm
Bishop B. (1964)	Reflex Control Of Abdominal Muscles During Positive-Pressure Breathing.	About respiratory function of the diaphragm
Bishop B. et al. (1972)	Vagal Control Of Ventilation And Respiratory Muscles During Elevated Pressures In The Cat.	About respiratory function of the diaphragm
Bloch S. et al. (1991	Specific Respiratory Patterns Distinguish Among Human Basic Emotions.	About respiratory function of the diaphragm
Bloch-Salisbury E. et al. (2003)	Mechanical Chest-Wall Vibration Does Not Relieve Air Hunger.	Medical study

Bonora M. et al. (1985)	Changes In Upper Airway Muscle Activity Related To Head Position In Awake Cats.	About respiratory function of the diaphragm
Boyle MJ. et al. (1999)	Transhiatal Versus Transthoracic Esophagectomy: Complication And Survival Rates.	Surgical study
Brack T. (2009)	Breathlessness: Different Causes And Qualities Of Dyspnea.	About respiratory function of the diaphragm / Other language than Dutch or English
Braginsky L. et al. (2015)	Management Of Perforated Essure With Migration Into Small And Large Bowel Mesentery	Surgical / Medical study
Bramante CT. et al. (2011)	Suitability Of The Pericardiophrenic Veins For Phrenic Nerve Stimulation: An Anatomic Study.	Cadaveric study
Brancatisano A. et al. (1989)	Postural Changes In Spontaneous And Evoked Regional Diaphragmatic Activity In Dogs.	Study in dogs
Brandão DC. et al. (2012)	Chest Wall Regional Volume In Heart Failure Patients During Inspiratory Loaded Breathing.	About respiratory function of the diaphragm
Brice AG. et al. (1991)	Effects Of Increased End-Expiratory Lung Volume On Breathing In Awake Ponies.	About respiratory function of the diaphragm
Bruce EN. et al. (1986)	High-Frequency Oscillations In Human Electromyograms During Voluntary Contractions.	About respiratory function of the diaphragm
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Budzińska K. et al. (1985)	Release Of Expiratory Muscle Activity By Graded Focal Cold Block In The Medulla.	Medical study
Budzińska K. et al. (1985)	Effects Of Graded Focal Cold Block In The Solitary And Para-Ambigual Regions Of The Medulla In The Cat.	Medical study
Bumm R. et al. (1993)	Endodissection Of The Thoracic Esophagus. Technique And Clinical Results In Transhiatal Esophagectomy.	Surgical study
Burri E. et al. (2014)	Mechanisms Of Postprandial Abdominal Bloating And Distension In Functional Dyspepsia.	No assessment of the diaphragm
Butler JE. (2007)	Drive To The Human Respiratory Muscles.	About respiratory function of the diaphragm
Butler JE. et al. (2014)	The Neural Control Of Human Inspiratory Muscles.	About respiratory function of the diaphragm
Byeon K. et al. (2012)	The Respons Of The Vena Cava To Abdominal Breathing	About respiratory function of the diaphragm
Campbell GR. et al. (2013)	Mitochondrial DNA Deletions And Depletion Within Paraspinal Muscles.	No assessment of the diaphragm
Carrier DR. et al. (1989)	Ventilatory Action Of The Hypaxial Muscles Of The Lizard Iguana Iguana: A Function Of Slow Muscle.	No assessment of the diaphragm
Casaroli AA. et al. (2011)	The Effects Of Pneumoperitoneum And Controlled Ventilation On Peritoneal Lymphatic Bacterial Clearance: Experimental Results In Rats.	Medical study
Celli B. (1993)	Respiratory Muscle Strength After Upper Abdominal Surgery.	Surgical study
Chasen MH. et al. (1998)	Venous Chest Anatomy: Clinical Implications.	Medical study
Chatham K. et al. (2004)	A Short-Term Comparison Of Two Methods Of Sputum Expectoration In Cystic Fibrosis.	No assessment of the diaphragm
Chetta A. et al. (2007)	Assessment And Monitoring Of Ventilatory Function And Cough Efficacy In Patients With Amyotrophic Lateral Sclerosis.	About respiratory function of the diaphragm
Chi I. et al. (1980)	Technical Failures In Tubal Ring Sterilization: Incidence, Perceived Reasons, Outcome, And Risk Factors.	No assessment of the diaphragm
Coates Al. et al. (1981)	Ventilation, Respiratory Center Output, And Contribution Of The Rib Cage And Abdominal Components To Ventilation During CO2 Rebreathing In Children With Cystic Fibrosis.	About respiratory function of the diaphragm
Cobb MA. et al. (1994)	Neonatal Development Of The Diaphragm Of The Horse, Equus Caballus.	No assessment of the diaphragm
Cohen E. et al. (1995)	Is Voluntary Control Of Breathing Impaired In Patients With Chronic Obstructive Pulmonary Disease?	About respiratory function of the diaphragm
Corda M. et al. (1966)	Reflex And Cerebellar Influences On Alpha And On 'Rhythmic' And 'Tonic' Gamma Activity In The Intercostal Muscle.	No assessment of the diaphragm
Cossette I. et al. (2008)	Chest Wall Dynamics And Muscle Recruitment During Professional Flute Playing.	About respiratory function of the diaphragm
Costa D. et al. (2003)	Evaluation Of Respiratory Muscle Strength And Thoracic And Abdominal Amplitudes After A Functional Reeducation Of Breathing Program For Obese Individuals.	About respiratory function of the diaphragm / other language than Dutch or English
Cotter LA. et al. (2001)	Effects Of Postural Changes And Vestibular Lesions On Diaphragm And Rectus Abdominis Activity In Awake Cats.	About respiratory function of the diaphragm
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D'Angelo E. et. al. (2010)	Motor Control Of The Diaphragm In Anesthetized Rabbits.	About respiratory function of the diaphragm
Dahmane R. et al. (2009)	Anatomy Of The Ligamentum Venosum Arantii And Its Contribution To The Left Hepatic Vein And Common Trunk Control. A Study On Cadaveric Livers.	Medical study
Daniel RK. et al. (1978)	The Great Potential Of The Intercostal Flap For Torso Reconstruction.	Medical study
Davis GM. et al. (1987)	Pulmonary And Chest Wall Mechanics In The Control Of Respiration In The Newborn.	About respiratory function of the diaphragm
De Rango P. et al. (2010)	Two-Stage Safe Repair Of Aortobronchial Fistula.	Surgical study
De Troyer A. et al. (1985)	Mechanics Of Intercostal Space And Actions Of External And Internal Intercostal Muscles.	No assessment of the diaphragm
De Troyer A. et al. (1987)	Effect Of Posture On Expiratory Muscle Use During Breathing In The Dog.	No assessment of the diaphragm
De Troyer A. et al. (2005)	Interaction Between The Canine Diaphragm And Intercostal Muscles In Lung Expansion.	About respiratory function of the diaphragm
Decramer M. et al. (1986)	Respiratory And Postural Changes In Intercostal Muscle Length In Supine Dogs.	No assessment of the diaphragm

Delhez L. (1985)	Stimulation-Detection Electromyography In Kinetic And Postural Abnormalities Of The Diaphragm.	Other language than Dutch or English
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Dent j. (1987)	Recent Views On The Pathogenesis Of Gastro-Oesophageal Reflux Disease.	No assessment of the diaphragm / review
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Dronkers J. et al. (2008)	Prevention Of Pulmonary Complications After Upper Abdominal Surgery By Preoperative Intensive Inspiratory Muscle Training: A Randomized Controlled Pilot Study.	About respiratory function of the diaphragm
Drummond GB. (1984)	Factors Influencing The Control Of Breathing.	About respiratory function of the diaphragm / no abstract availible
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Dumont AE. et al. (1986)	Increased Survival From Peritonitis After Blockade Of Transdiaphragmatic Absorption Of Bacteria.	Medical study
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Ebenbichler GR. et al. (2001)	Sensory-Motor Control Of The Lower Back: Implications For Rehabilitation.	No assessment of the diaphragm
Engel R. et al. (2011)	The Role Of Spinal Manipulation, Soft-Tissue Therapy, And Exercise In Chronic Obstructive Pulmonary Disease: A Review Of The Literature And Proposal Of An Anatomical Explanation.	Review
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Estenne M. et al. (1983)	Chest Wall Stiffness In Patients With Chronic Respiratory Muscle Weakness.	About respiratory function of the diaphragm
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Faghy MA. et al. (2014)	Thoracic Load Carriage-Induced Respiratory Muscle Fatigue.	About respiratory function of the diaphragm
Farber JP. (1986)	Differential Recruitment Of Expiratory Muscles During Opossum Development.	No assessment of the diaphragm
Farkas GA. et al. (1988)	Mechanical Role Of Expiratory Muscles During Breathing In Upright Dogs.	No assessment of the diaphragm
Farkas GA. et al. (1989)	Expiratory Muscle Contribution To Tidal Volume In Head-Up Dogs.	About respiratory function of the diaphragm
Farkas GA. et al. (1990)	Mechanical Role Of Expiratory Muscles During Breathing In Prone Anesthetized Dogs.	About respiratory function of the diaphragm
Farkas GA. et al. (1993)	Functional Significance Of Expiratory Muscles During Spontaneous Breathing In Anesthetized Dogs.	About respiratory function of the diaphragm
Feldblum PJ. et al. (1986)	Technical Failures In Female Sterilization Using The Tubal Ring: A Case-Control Analysis.	No assessment of the diaphragm
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Goodman MD. et al. (2005)	Forequarter Amputation For Recurrent Breast Cancer: A Case Report And Review Of The Literature.	Surgical study / review
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Greer JJ. et al. (2000)	Structure Of The Primordial Diaphragm And Defects Associated With Nitrofen-Induced CDH.	Medical study
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Grunninger B. (1955)	Vagal Respiratory Control From The Diaphragm And Abdomen.	Medical study / other language than Dutch or English
Guillebaud J. et al. (1980)	Intrauterine Devices: Present And Future.	No assessment of the diaphragm
Gullino D. (1979)	Posterior Gastro-Esophago-Phreno-Plasty (PGEPP) In The Treatment Of Hiatal Hernia And Of Esophagogastric Reflux. Experience In Over 500 Cases. Anterior Gastro-Esophago-Phreno-Plasty (AGEPP) In The Prevention Of Sliding Hiatal Hernia And Of Esophagogastric Reflux. Experience In Over 300 Cases.	Medical study / other language than Dutch or English
Gunn HM. et al. (1992)	Incidence Of Sarcocysts In Skeletal Muscles Of Horses.	Medical study
Habib MP. et al. (1978)	Influence Of The Panting Technique On The Plethysmographic Measurement Of Thoracic Gas Volume.	About respiratory function of the diaphragm
Hager WD. et al. (1979)	Pelvic Colonization With Actinomyces In Women Using Intrauterine Contraceptive Devices.	No assessment of the diaphragm
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Haimov-Kochman R. et al. (2003)	Intraperitoneal Levonorgestrel-Releasing Intrauterine Device Following Uterine Perforation: The Role Of Progestins In Adhesion Formation.	No assessment of the diaphragm
Hämäläinen RP. et al. (1978)	A Hierarchical Goal-Seeking Model Of The Control Of Breathing. Part I: Model Description.	About respiratory function of the diaphragm / no abstract available
Hamaoui A. et al. (2010)	Respiratory Disturbance To Posture Varies According To The Respiratory Mode.	About respiratory function of the diaphragm
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Hixon TJ. et al. (2006)	A Clinical Method For The Detection And Quantification Of Quick Respiratory Hyperkinesia.	About respiratory function of the diaphragm
Hollstien SB. et al. (1991)	Role Of Vagal Afferents In The Control Of Abdominal Expiratory Muscle Activity In The Dog.	No assessment of the diaphragm
Holness MJ. et al. (1990)	Glucose Utilization In Heart, Diaphragm And Skeletal Muscle During The Fed-To-Starved Transition.	Medical study
Hu F. et al. (1985)	Contraction-Dependent Modulations In Regional Diaphragmatic Blood Flow.	No assessment of the diaphragm
Hudgel DW. et al. (1988)	Alteration In Obstructive Apnea Pattern Induced By Changes In Oxygen- And Carbon-Dioxide-Inspired Concentrations.	Medical study
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Hurych J. et al. (1975)	Biosynthesis Of Collagen During The Life Cycle Of Human Diploid Cell Lines.	No assessment of the diaphragm
Hussain SN. (1996)	Regulation Of Ventilatory Muscle Blood Flow.	Medical study
Hussain SN. et al. (1985)	Inspiratory Muscle Function With Restrictive Chest Wall Loading During Exercise In Normal Humans.	About respiratory function of the diaphragm
Hussain SN. et al. (1985)	Effects Of Separate Rib Cage And Abdominal Restriction On Exercise Performance In Normal Humans.	About respiratory function of the diaphragm
Iizuka M. (2003)	GABAA And Glycine Receptors In Regulation Of Intercostal And Abdominal Expiratory Activity In Vitro In Neonatal Rat.	No assessment of the diaphragm
Iscoe S. (1998)	Control Of Abdominal Muscles.	No assessment of the diaphragm
Ismail AH. et al. (1986)	Structural Changes Of The Diaphragmatic Peritoneum In Patients With Schistosomal Hepatic Fibrosis: Its Relation To Ascites.	No assessment of the diaphragm
Jansen AH. et al. (1983)	Development Of Respiratory Control.	About respiratory function of the diaphragm / no abstract available
Kakarlapudi GV. et al. (2002)	The Effect Of Diaphragmatic Stressors On Recurrent Hiatal Hernia.	No assessment of the diaphragm
Kanamaru A. et al. (1999)	Movement Related Cortical Source For Elbow Flexion In Patients With Branchial Plexus Injury After Intercostal-Musculocutaneous Nerve Crossing.	No assessment of the diaphragm
Karoui M. et al. (2007)	En Bloc Stapled Diaphragmatic Resection For Local Invasion During Hepatectomy: A Simple Technique Without Opening The Pleural Cavity.	Surgical study
Katsura M. et al. (2015)	Preoperative Inspiratory Muscle Training For Postoperative Pulmonary Complications In Adults Undergoing Cardiac And Major Abdominal Surgery	About respiratory function of the diaphragm
Kaufman MH. (1992)	Postcranial Morphological Features Of Homozygous Tetraploid Mouse Embryos.	No assessment of the diaphragm
Kawada M. et al. (2007)	Potential Foramen To Allow Communication Between The Pleural Cavity And Retroperitoneal Space During Laparoscopic Surgery: A Cadaver Study Of Bochdalek's Triangle.	Surgical study
Kawahara K. et al. (1988)	Parallel Suppression Of Extensor Muscle Tone And Respiration By Stimulation Of Pontine Dorsal Tegmentum In Decerebrate Cat.	Medical study
Kawamoto H. et al. (2008)	Evaluation Of The Diaphragm In Patients With COPD (Emphysema Dominant Type) By Abdominal Ultrasonography.	About respiratory function of the diaphragm / other language than Dutch or English
Key J. et al. (2013)	'The Core': Understanding It, And Retraining Its Dysfunction.	Review
Kim C. et al. (1988)	Burn Injury To Rat Increases Nicotinic Acetylcholine Receptors In The Diaphragm.	Medical study
Kim HK. et al. (2005)	Infected Infradiaphragmatic Retroperitoneal Extralobar Pulmonary Sequestration: A Case Report.	Medical study
Kinnear W. et al. (1989)	Ventilatory Compensation For Changes In Posture After Human Heart-Lung Transplantation.	About respiratory function of the diaphragm
Kirkwood PA. (1995)	Synaptic Excitation In The Thoracic Spinal Cord From Expiratory Bulbospinal Neurones In The Cat.	No assessment of the diaphragm
Kirov K. et al. (2001)	Differential Sensitivity Of Abdominal Muscles And The Diaphragm To Mivacurium: An Electromyographic Study.	Medical study
Kitaoka H. et al. (2010)	The Diaphragm: A Hidden But Essential Organ For The Mammal And The Human.	Review
Knook LM. et al. (1999)	Lung Function Abnormalities And Respiratory Muscle Weakness In Children With Juvenile Chronic Arthritis.	About respiratory function of the diaphragm
Kobayashi C. et al. (2003)	Electromyographic Activity Of Human Triangularis Sterni Muscles During Thoracic Rotation.	No assessment of the diaphragm
Kocum E. et al. (2011)	Transdiaphragmatic Blockage Of The Lymphatic May Reduce Bacterial Translocation.	Surgical / medical study
Konno K. et al. (1992)	Dyspnea And Rib Cage Distortion In Postural Changes.	No assessment of the diaphragm / other language than Dutch or English
Korst RJ. et al. (1997)	Atraumatic Gastric Transposition After Transhiatal Esophagectomy.	Surgical study
Kouraklis G. et al. (2005)	Myoplasty Versus Omentoplasty In The Surgical Treatment Of Hydatidosis Of The Liver Dome.	Surgical study
Kulkarni SR. et al. (2010)	Pre-Operative Inspiratory Muscle Training Preserves Postoperative Inspiratory Muscle Strength Following Major Abdominal Surgery - A Randomised Pilot Study.	About respiratory function of the diaphragm
Lai-Fook SJ. et al. (2005)	Transdiaphragmatic Transport Of Tracer Albumin From Peritoneal To Pleural Liquid Measured In Rats.	Medical study
Lang-Lazdunski L. et al. (1997)	Role Of Videothoracoscopy In Chest Trauma.	Surgical study
Langevin PB. et al. (1999)	Synchronization Of Radiograph Film Exposure With The Inspiratory Pause. Effect On The Appearance Of Bedside Chest Radiographs In Mechanically Ventilated Patients.	About respiratory function of the diaphragm

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Leduc D. et al. (2009)	Mechanism Of Increased Inspiratory Rib Elevation In Ascites.	No assessment of the diaphragm
Leduc D. et al. (2013)	Function Of The Canine Inspiratory Muscle Pump In Pleural Effusion: Influence Of Body Position.	About respiratory function of the diaphragm
Leevers AM. et al. (1991	Effect Of Lung Inflation And Upright Posture On Diaphragmatic Shortening In Dogs.	About respiratory function of the diaphragm
Levsky JM. et al. (2005)	Incidental Detection Of A Transmigrated Intrauterine Device.	No assessment of the diaphragm
Lima IN. et al (2014)	Acute Effects Of Volume-Oriented Incentive Spirometry On Chest Wall Volumes In Patients After A Stroke.	About respiratory function of the diaphragm
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Lipski J. et al. (1986)	An Electrophysiological Investigation Of Propriospinal Inspiratory Neurons In The Upper Cervical Cord Of The Cat.	No assessment of the diaphragm
Lo Mauro A. et al. (2010)	Abdominal Volume Contribution To Tidal Volume As An Early Indicator Of Respiratory Impairment In Duchenne Muscular Dystrophy.	About respiratory function of the diaphragm
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Lunardi AC. et al. (2015)	Comparison Of Lung Expansion Techniques On Thoracoabdominal Mechanics And Incidence Of Pulmonary Complications After Upper Abdominal Surgery: A Randomized And Controlled Trial.	About respiratory function of the diaphragm
Lunn RH. et al. (2015)	Dem Bones	No abstract or full text available
Macefield G. et al. (1986)	Inspiratory Augmentation During Asphyxic Hyperpnoea And Gasping: Proprioceptive Influences.	No assessment of the diaphragm
Malakhov MV. et al. (2014)	Assessment Of Influence Of Breath Holding And Hyperventilation On Human Postural Stability With Spectral Analysis Of Stabilographic Signal.	About respiratory function of the diaphragm / other language than Dutch or English
Malhotra SK. et al. (2006)	Incidence And Types Of Arrhythmias After Mediastinal Manipulation During Transhiatal Esophagectomy.	Surgical study
Martin J. et al. (1980)	The Role Of Respiratory Muscles In The Hyperinflation Of Bronchial Asthma.	About respiratory function of the diaphragm
Massion J. et al. (1960)	Postural Function Of The Respiratory Muscles.	Other language than Dutch or English / no abstract or full tekst available
Masubuchi Y. et al. (2001)	Relation Between Neck Accessory Inspiratory Muscle Electromyographic Activity And Lung Volume.	No assessment of the diaphragm / other language than Dutch or English
Matthes G. et al. (2006)	Surgical Management Of Abdominal Injury.	Surgical study / other language than Dutch or English
McCabe RE. et al. (1989)	Trypanosoma Cruzi: Explant Organ Cultures From Mice With Chronic Chagas' Disease.	No assessment of the diaphragm
McLaughlin R. et al. (2000)	Diaphragmatic Dysfunction Secondary To Experimental Lower Torso Ischaemia-Reperfusion Injury Is Attenuated By Thermal Preconditioning.	Medical study
Merchav R. et al. (2005)	Expression Of Relaxin Receptor LRG7, Canine Relaxin, And Relaxin-Like Factor In The Pelvic Diaphragm Musculature Of Dogs With And Without Perineal Hernia.	No assessment of the diaphragm
Michailova KN. et al. (2001)	Postinflammatory changes of the diaphragmatic stomata	Medical study
Miller JD. et al. (2002)	Cardiorespiratory Effects Of Inelastic Chest Wall Restriction.	No assessment of the diaphragm
Miller MA. et al. (2009)	Abdominal Twitching Due To Inadequate Stitching.	Surgical study / no abstract available
Miller RJ. et al. (2002)	Attenuation Coefficient And Propagation Speed Estimates Of Intercostal Tissue As A Function Of Pig Age.	No assessment of the diaphragm
Miniaev VI. et al. (2005)	Voluntary Control Of Thoracic And Abdominal Respiratory Movements.	About respiratory function of the diaphragm / other language than Dutch or English
Miserocchi G. (1997)	Physiology And Pathophysiology Of Pleural Fluid Turnover.	No assessment of the diaphragm
Miyake Y. et al. (2013)	Core Exercises Elevate Trunk Stability To Facilitate Skilled Motor Behavior Of The Upper Extremities.	No assessment of the diaphragm
Miyamoto K. et al. (2002)	Fast MRI Used To Evaluate The Effect Of Abdominal Belts During Contraction Of Trunk Muscles.	No assessment of the diaphragm
Miyashita M. et al. (2003)	Respiratory Control During Postural Changes In Anesthetized Cats.	About respiratory function of the diaphragm
Mizuno S. et al. (2013)	An Approach To The Intra-Thoracic Inferior Vena Cava Through The Abdominal Cavity Preparing For Total Hepatic Vascular Exclusion By Sagittal Diaphragmotomy.	Surgical study
Modell HI. et al. (1984)	Influence Of The Chest Wall On Regional Intrapleural Pressure During Acceleration (+Gz) Stress.	No assessment of the diaphragm
Moneley D. et al. (2001)	Preoperative Treatment With Recombinant Human Growth Hormone Prevents Ischemia Reperfusion-Induced Diaphragmatic Dysfunction.	About respiratory function of the diaphragm

Moote CA. et al. (1986)	Ventilatory Compensation For Continuous Inspiratory Resistive And Elastic Loads During Halothane Anesthesia In Humans.	About respiratory function of the diaphragm
Moran J. et al. (1986)	Transperitoneal Absorption Of Intralipid In Rats: Total Serum Fatty Acids And Triglyceride After Absorption.	No assessment of the diaphragm
Moreno MA. et al. (2007)	Effect Of A Muscle Stretching Program Using The Global Postural Reeducation Method On Respiratory Muscle Strength And Thoracoabdominal Mobility Of Sedentary Young Males.	No assessment of the diaphragm / other language than Dutch or English
Mori RL. et al. (2001)	Role Of The Medial Medullary Reticular Formation In Relaying Vestibular Signals To The Diaphragm And Abdominal Muscles.	Medical study
Moriondo A. et al. (2007)	Regional Recruitment Of Rat Diaphragmatic Lymphatics In Response To Increased Pleural Or Peritoneal Fluid Load.	Medical study
Nagy JA. et al. (1995)	Pathogenesis Of Ascites Tumor Growth: Angiogenesis, Vascular Remodeling, And Stroma Formation In The Peritoneal Lining.	No assessment of the diaphragm
Newman SL. et al. (1986)	In Vivo Length And Shortening Of Canine Diaphragm With Body Postural Change.	About respiratory function of the diaphragm
Ninane V. et al. (1985)	Mechanism Of Triangularis Sterni Shortening During Expiration In Dogs.	No assessment of the diaphragm
Nudler SI. et al. (2005)	Testosterone Modulates Ca(V2.2) Calcium Channels' Functional Expression At Rat Levator Ani Neuromuscular Junction.	No assessment of the diaphragm
O'sullivan PB. et al. (2007)	Changes In Pelvic Floor And Diaphragm Kinematics And Respiratory Patterns In Subjects With Sacroiliac Joint Pain Following A Motor Learning Intervention: A Case Series.	Not about the role of the diaphragm in trunk stability
O'Toole MJ. et al. (1996)	Pneumothorax And Wound Dehiscence Related To Collagenase Deregulation: Treatment With Diphenylhydantoin.	Medical study
Obayashi H. et al. (2012)	Effects Of Respiratory-Muscle Exercise On Spinal Curvature.	About spinal curvature
Okumus M. et al. (2006)	Muscle Performance In Patients With Fibromyalgia.	No assessment of the diaphragm
Okuro RT. et al. (2011)	Exercise Capacity, Respiratory Mechanics And Posture In Mouth Breathers.	About respiratory function of the diaphragm
Okuro RT. et al. (2011)	Mouth Breathing And Forward Head Posture: Effects On Respiratory Biomechanics And Exercise Capacity In Children.	About respiratory function of the diaphragm
Oliveira Da Silva AM. et al. (2014)	Surface Electromyography For Respiratory Assessment Of Liver Transplant Candidates, Healthy Subjects And After Chevron Post-Operative Incision.	About respiratory function
Palussière J. et al. (2013)	Retrospective Review Of Thoracic Neural Damage During Lung Ablation - What The Interventional Radiologist Needs To Know About Neural Thoracic Anatomy.	Surgical study / review
Parmeggiani PL. et al. (1978)	Regulation Of The Activity Of Respiratory Muscles During Sleep.	About respiratory function of the diaphragm
Parshin VD. et al. (2013)	Surgery Of The Diaphragm In The Planned Thoracic Surgery.	Surgical study / other language than Dutch or English
Patten RM. et al. (1991)	Ligamentous Compression Of The Celiac Axis: CT Findings In Five Patients.	No assessment of the diaphragm
Penafortes JTS. et al. (2013)	Relationship Between Body Balance, Lung Function, Nutritional Status And Functional Capacity In Adults With Cystic Fibrosis	About respiratory function of the diaphragm
Peoples GE. et al. (2016)	The Effects Of Thoracic Load Carriage On Maximal Ambulatory Work Tolerance And Acceptable Work Durations	About respiratory function of the diaphragm
Polaner DM. et al. (1993)	Thoracic Epidural Anesthesia Increases Diaphragmatic Shortening After Thoracotomy In The Awake Lamb.	Medical study
Pontoppidan H. et al. (1972)	Acute Respiratory Failure In The Adult. 2.	About respiratory function of the diaphragm
Popov IuA. (1986)	Hemodynamics In The Region Of The Visceral Branches Of The Abdominal Aorta In Diffuse Suppurative Peritonitis.	No assessment of the diaphragm / other language than Dutch or English
Prevo M. et al. (1980)	Local Effects Of Intrauterine Contraceptives Placed Within The Peritoneal Cavities Of Rabbits.	No assessment of the diaphragm
Ratten GJ. (1971)	Removal Of An Intraperitoneal Intrauterine Device Under Laparoscopic Control.	No assessment of the diaphragm / no abstract or full tekst available
Redline S. et al. (1987)	Influence Of Upper Airway Sensory Receptors On Respiratory Muscle Activation In Humans.	About respiratory function of the diaphragm
Rehder K. et al. (1998)	Postural Changes In Respiratory Function.	About respiratory function of the diaphragm
Reis FJ. et al. (1994)	Diaphragmatic Activity And Ventilation In Preterm Infants. I. The Effects Of Sleep State.	About respiratory function of the diaphragm
Remiche G. et al. (2013)	Postural Effects On Lung And Chest Wall Volumes In Late Onset Type II Glycogenosis Patients	About respiratory function of the diaphragm
Rimmer KP. et al. (1995)	Interaction Between Postural And Respiratory Control Of Human Intercostal Muscles.	No assessment of the diaphragm
Road JD. (1990)	Phrenic Afferents And Ventilatory Control.	Medical study
Road JD. et al. (1984)	Diaphragm Function And Respiratory Response After Upper Abdominal Surgery In Dogs.	About respiratory function of the diaphragm
Rolla G. et al. (1971)	Hysterophlebography In Patients With Intrauterine Devices.	No assessment of the diaphragm / other

		language than Dutch or English
Romagnoli I. et al. (2004)	Chest Wall Kinematics And Respiratory Muscle Action In Ankylosing Spondylitis Patients.	About respiratory function of the diaphragm
Romagnoli I. et al. (2004)	Chest Wall Kinematics And Respiratory Muscle Coordinated Action During Hypercapnia In Healthy Males.	About respiratory function of the diaphragm
Romanovsky AA. et al. (2000)	Lipopolysaccharide Transport From The Peritoneal Cavity To The Blood: Is It Controlled By The Vagus Nerve?	No assessment of the diaphragm
Rosenberg PH. et al. (1984)	Comparison Of Intramuscular Analgesia, Intercostal Block, Epidural Morphine And On-Demand-I.V.-Fentanyl In The Control Of Pain After Upper Abdominal Surgery.	No assessment of the diaphragm
Rouaud T. et al. (2009)	Experimental Study Of A Late Response Recorded From The Thoracic Wall After Phrenic Nerve Stimulation.	Medical study
Saitou M. et al. (2011)	A Case Of Postural Hypoxemie With A Final Diagnosis Of Myasthenia Gravis.	No assessment of the diaphragm / other language than Dutch or English
Sansone GR. et al. (1997)	Cardiovascular Responses To Vaginocervical Stimulation In The Spinal Cord-Transected Rat.	No assessment of the diaphragm
Santis-Isolan PM et al. (2009)	Diaphragm Frozen Homograft For Rats' Abdominal Wall Defects Repair.	No assessment of the diaphragm / other language than Dutch or English
Saraswat L. et al. (2008)	Caesarean Section And Tubal Infertility: Is There An Association?	No assessment of the diaphragm
Saunders SW. et al. (2004)	Postural And Respiratory Activation Of The Trunk Muscles Changes With Mode And Speed Of Locomotion.	No assessment of the diaphragm
Shakhbazian ES. (1965)	On Revascularization Of The Myocardium.	No assessment of the diaphragm / other language than Dutch or English
Shannon R. (1976)	Respiratory Frequency Control During Hypercapnia In Vagotomized, Anesthetized Cats.	About respiratory function of the diaphragm
Sharp JT. et al. (1980)	Postural Relief Of Dyspnea In Severe Chronic Obstructive Pulmonary Disease.	About respiratory function of the diaphragm / no abstract available
Shaw BS. et al. (2011)	Pulmonary Function And Abdominal And Thoracic Kinematic Changes Following Aerobic And Inspiratory Resistive Diaphragmatic Breathing Training In Asthmatics.	About respiratory function of the diaphragm
Shurtleff E. et al. (2012)	Posterior Intercostal Artery Tortuosity And Collateral Branch Points: A Cadaveric Study.	Cadaveric study
Siafakas NM. et al. (1993)	Effect Of Aminophylline On Respiratory Muscle Strength After Upper Abdominal Surgery: A Double Blind Study.	Medical study
Siafakas NM. et al. (1999)	Effects Of Surgery On The Function Of The Respiratory Muscles.	Surgical study
Siddigi MS. et al. (2015)	Polytrauma To Right Diaphragm, Descending Thoracic Aorta, And Innominate Artery.	Surgical / medical study
Simonneau G. et al. (1983)	Diaphragm Dysfunction Induced By Upper Abdominal Surgery. Role Of Postoperative Pain.	Surgical / medical study
Singh B. et al. (1999)	Effect Of Asbestos-Related Pleural Fibrosis On Excursion Of The Lower Chest Wall And Diaphragm.	Medical study
Skladal J. et al. (1969)	Postural Activity Of The Diaphragm In Human.	Other language than Dutch or Englisch / no abstract or full tekst available
Skladal J. et al. (1970)	Postural Function Of Diaphragm In Man.	Other language than Dutch or Englisch
Skladal J. et al. (1978)	Some Remarks Concerning The Postural Activity Of The Diaphragm In Man.	No abstract or full tekst available
Skladal J. et al. (1980)	Postural Function Of The Human Diaphragm As A Link In Orthostatic Regulation.	Other language than Dutch or Englisch
Smyrniotis V. et al. (2005)	Combination Of Diaphragmatic Plication With Major Abdominal Surgery In Patients With Phrenic Nerve Palsy.	Surgical study
Soares SM. et al. (2013)	Pulmonary Function And Physical Performance Outcomes With Preoperative Physical Therapy In Upper Abdominal Surgery: A Randomized Controlled Trial.	About respiratory function of the diaphragm
Sohn DK. et al. (2010)	Reducing The Unexpectedly High Rate Of Injuries Caused By NOTES Gastrotomy Creation.	No assessment of the diaphragm
Sood A. et al. (2015)	Robot-Assisted Hepatic Mobilization And Control Of Suprahepatic Infradiaphragmatic Inferior Vena Cava For Level 3 Vena Caval Thrombectomy: An IDEAL Stage 0 Study.	No assessment of the diaphragm
Sprung J. et al. (1991)	Diaphragm Dysfunction And Respiratory Insufficiency After Upper Abdominal Surgery.	About respiratory function of the diaphragm
Steele M. et al. (1975)	Advances In Management Of Splenic Injuries	No assessment of the diaphragm
Stener B. et al. (1977)	Extirpation Of Tumors Located Near The Thoracic Cage. A Method For Increasing The Margin Of Healthy Tissue On The Deep Side Of The Tumor.	No assessment of the diaphragm
Stigol LC. et al. (1966)	Voluntary Control Of The Diaphragm In One Subject.	About respiratory function of the diaphragm / no abstract or full tekst available
Sugarbaker PH. (2007)	Peritoneum As The First-Line Of Defense In Carcinomatosis.	No assessment of the diaphragm
Tansley P. et al. (2006)	A Novel Modification Of Omental Transposition To Reduce The Risk Of Gastrointestinal Herniation Into The Chest.	No assessment of the diaphragm
Taylor DB. et al. (1970)	Ion Exchange Processes At The Neuromuscular Junction Of Voluntary Muscle.	No assessment of the diaphragm

Teotico GA. et al. (2001)	Attenuation Coefficient Estimates Of Mouse And Rat Chest Wall.	No assessment of the diaphragm
Terada N. et al. (1993)	Postural Changes In Venous Pressure Gradients In Anesthetized Monkeys.	No assessment of the diaphragm
Thorburn J. et al. (1986)	Background Factors Of Ectopic Pregnancy. II. Risk Estimation By Means Of A Logistic Model.	No assessment of the diaphragm
Thorburn J. et al. (1986)	Background Factors Of Ectopic Pregnancy. I. Frequency Distribution In A Case-Control Study.	No assessment of the diaphragm
Tobin MJ. et al. (1994)	Pathophysiology Of Failure To Wean From Mechanical Ventilation.	About respiratory function of the diaphragm
Tojima H. et al. (1992)	Spontaneous Ventilation And Respiratory Motor Output During Carbachol-Induced Atonia Of REM Sleep In The Decerebrate Cat.	About respiratory function of the diaphragm
Tolins S. (1973)	Transthoracic Or Transabdominal Fundoplication.	No assessment of the diaphragm / no abstract available
Tomczak CR. et al. (2013)	Modulation Of Chest Wall Intermuscular Coherence: Effects Of Lung Volume Excursion And Transcranial Direct Current Stimulation	About respiratory function of the diaphragm
Towa RT. et al. (2002)	Attenuation Coefficient And Propagation Speed Estimates Of Rat And Pig Intercostal Tissue As A Function Of Temperature.	No assessment of the diaphragm
Turgeman T. et al. (2008)	Prevention Of Muscle Fibrosis And Improvement In Muscle Performance In The Mdx Mouse By Halofuginone.	No assessment of the diaphragm
Turrentine MW. et al., 1990	Effect of omental, intercostal, and internal mammary artery pedicle wraps on bronchial healing	No assessment of the diaphragm
Tzelepis GE. et al. (1989)	Chest Wall Distortion In Patients With Flail Chest.	Medical study
Ugalde V. et al. (2001)	Respiratory Abdominal Muscle Recruitment And Chest Wall Motion In Myotonic Muscular Dystrophy.	No assessment of the diaphragm
Ünlü E. et al. (2012)	Diaphragmatic Movements In Ankylosing Spondylitis Patients And Their Association With Clinical Factors: An Ultrasonographic Study.	About respiratory function of the diaphragm
Upton J. et al. (2012)	Correlation Between Perceived Asthma Control And Thoraco-Abdominal Asynchrony In Primary Care Patients Diagnosed With Asthma.	About respiratory function of the diaphragm
Uribe JM. et al. (1992)	Influence Of Exercise Training On The Oxidative Capacity Of Rat Abdominal Muscles.	No assessment of the diaphragm
Valenza MC. et al. (2015)	The Effects Of Doming Of The Diaphragm In Subjects With Short-Hamstring Syndrome: A Randomized Controlled Trial.	No assessment of the diaphragm
Valera FC. et al. (2003)	Muscular, Functional And Orthodontic Changes In Pre School Children With Enlarged Adenoids And Tonsils.	No assessment of the diaphragm
Vandevenne A. et al. (1993)	Respiratory Rehabilitation In Patients With Obstructive Ventilatory Disease.	About respiratory function of the diaphragm / other language than Dutch or English
Vecchio LM. et al. (2010)	State-Dependent Vs. Central Motor Effects Of Ethanol On Breathing.	Medical study / about respiratory function of the diaphragm
Vezhnin VF. et al. (1991)	Use Of Manual Reflexotherapy For Correcting Biomechanical Changes In The Chest And The Functional Status Of The Diaphragmatic Neuromuscular Complex In Patients With Tuberculosis.	Other language than Dutch or English
Von Euler C. (1973)	The Role Of Proprioceptive Afferents In The Control Of Respiratory Muscles.	Medical study
Watchko JF. et al. (1991)	The Ventilatory Pump: Neonatal And Developmental Issues.	About respiratory function of the diaphragm
Wens SC. et al. (2015)	Lung MRI And Impairment Of Diaphragmatic Function In Pompe Disease.	About respiratory function of the diaphragm
White JE. et al. (1995)	Respiratory Muscle Activity And Oxygenation During Sleep In Patients With Muscle Weakness.	About respiratory function of the diaphragm
Won YH. et al. (2015)	Postural Vital Capacity Difference With Aging In Duchenne Muscular Dystrophy	About respiratory function of the diaphragm
Wu A. et al. (2006)	Respiratory Muscle Activity And Respiratory Obstruction After Abdominal Surgery.	About respiratory function of the diaphragm
Xie AL. et al. (1991)	Chemical And Postural Influence On Scalene And Diaphragmatic Activation In Humans.	About respiratory function of the diaphragm
Yates BJ. et al. (2002)	Role Of The Vestibular System In Regulating Respiratory Muscle Activity During Movement.	About respiratory function of the diaphragm
Yi LC. et al. (2008)	The Relationship Between Excursion Of The Diaphragm And Curvatures Of The Spinal Column In Mouth Breathing Children.	About spinal curvature
Yosef-Brauner O. et al. (2015)	Effect Of Physical Therapy On Muscle Strength, Respiratory Muscles And Functional Parameters In Patients With Intensive Care Unit-Acquired Weakness.	About respiratory function of the diaphragm
Zhang J. et al. (2013)	Feasibility Of Endoscopic Transumbilical Thoracic Sympathectomy In A Porcine Model.	No assessment of the diaphragm
Zhu LH. et al. (2013)	Embryonic NOTES Thoracic Sympathectomy For Palmar Hyperhidrosis: Results Of A Novel Technique And Comparison With The Conventional VATS Procedure.	No assessment of the diaphragm

TABLE 2B: Overview excluded studies and reason of exclusion Web of Science

Source	Title	Reason of exclusion
Abraham KA. et al. (2002)	Respiratory-Related Activation Of Human Abdominal Muscles During Exercise	No assessment of the diaphragm
Abuquerque-neto C. et al. (2010)	A Passive Model Of The Heat, Oxygen And Carbon Dioxide Transport In The Human Body	No assessment of the diaphragm
Allison GT. et al. (2008)	Feedforward Responses Of Transversus Abdominis Are Directionally Specific And Act Asymmetrically: Implications For Core Stability Theories	No assessment of the diaphragm
Almeida VP. et al. (2013)	Correlation Between Pulmonary Function, Posture, And Body Composition In Patients With Asthma	No assessment of the diaphragm
AmodieStorey C. et al. (1996)	Head Position And Its Effect On Pulmonary Function In Tetraplegic Patients	About respiratory function of the diaphragm
Anaclet C. et al. (2010)	Brainstem Circuitry Regulating Phasic Activation Of Trigeminal Motoneurons During Rem Sleep	No assessment of the diaphragm
Andrada L. et al. (2001)	Functional Breathing Evaluation In Patients With High Spinal Injury.	Other language than Dutch or English
Antozzi C. et al. (1994)	Late-Onset Riboflavin-Responsive Myopathy With Combined Multiple Acyl-Coenzyme-A Dehydrogenase And Respiratory-Chain Deficiency	No assessment of the diaphragm
Aschenbach R. et al. (2011)	Compression Of The Celiac Trunk Caused By Median Arcuate Ligament In Children And Adolescent Subjects: Evaluation With Contrast-Enhanced Mr Angiography And Comparison With Doppler Us Evaluation	Medical study
Aydin N. et al. (2008)	The Effect Of Severe Osteoporosis On Postural Deformities And Pulmonary Function Tests	About respiratory function of the diaphragm
Barbin ICC. et al. (2016)	Diaphragm Degeneration And Cardiac Structure In Mdx Mouse: Potential Clinical Implications For Duchenne Muscular Dystrophy	Medical study
Bartsch T. et al. (1999)	Hypoventilation Recruits Preganglionic Sympathetic Fibers With Inspiration-Related Activity In The Superior Cervical Trunk Of The Rat	About respiratory function of the diaphragm
Bayar B. et al. (2004)	The Short Term Effects Of An Exercise Programme As An Adjunct To An Orthosis In Neuromuscular Scoliosis	No assessment of the diaphragm
Beales DJ. et al. (2010)	The Effect Of Increased Physical Load During An Active Straight Leg Raise In Pain Free Subjects	No assessment of the diaphragm
Behr M. et al. (2010)	A Three-Dimensional Human Trunk Model For The Analysis Of Respiratory Mechanics	About respiratory function of the diaphragm
Belavy DL. et al. (2009)	Analysis Of Phasic And Tonic Electromyographic Signal Characteristics: Electromyographic Synthesis And Comparison Of Novel Morphological And Linear-Envelope Approaches	No assessment of the diaphragm
Bogerd S. et al. (2009)	Chest Physiotherapy Techniques - Can They Reduce Hyperinflation?	About respiratory function of the diaphragm
Boland B. et al. (1995)	Site-Dependent Pathological Differences In Smooth Muscles And Skeletal-Muscles Of The Adult Mdx Mouse	No assessment of the diaphragm
Breucking E. et al. (1993)	Anesthesia And Intensive-Care For A Patient With Mitochondrial Myopathy And A General Condition Similar To That Seen With Malignant Hyperthermia	No assessment of the diaphragm
Calabrese P. et al. (2000)	Postural Breathing Pattern Changes In Patients With Myotonic Dystrophy	About respiratory function of the diaphragm
Cheetham J. et al. (2009)	Role Of The Hypoglossal Nerve In Equine Nasopharyngeal Stability	Medical study
Claessens LPAM. (2009)	The Skeletal Kinematics Of Lung Ventilation In Three Basal Bird Taxa (Emu, Tinamou, And Guinea Fowl)	No assessment of the diaphragm
Cohen E. et al. (1995)	Is Voluntary Control Of Breathing Impaired In Patients With Chronic Obstructive Pulmonary-Disease	About respiratory function of the diaphragm
Corna S. et al. (1999)	Standing On A Continuously Moving Platform: Is Body Inertia Counteracted Or Exploited?	No assessment of the diaphragm
Courtney R. et al. (2009)	The Functions Of Breathing And Its Dysfunctions And Their Relationship To Breathing Therapy	About respiratory function of the diaphragm
Crommert AE. et al. (2008)	Trunk Muscle Coordination In Reaction To Load-Release In A Position Without Vertical Postural Demand	No assessment of the diaphragm
Cruz J. et al. (2015)	Global Functioning Of COPD Patients With And Without Functional Balance Impairment: An Exploratory Analysis Based On The Icf Framework	No assessment of the diaphragm
Danel-BV. et al. (2005)	Management And Treatment Of Respiratory Failure Associated With Amyotrophic Lateral Schlerosis.	About respiratory function of the diaphragm
De Paleville, DGLT. et al. (2014)	Respiratory Motor Function In Seated And Supine Positions In Individuals With Chronic Spinal Cord Injury	About respiratory function of the diaphragm
de Quadros LR. et al. (2017)	Physical therapy in a pregnant young woman with sequels of Guillain-Barre syndrome: case report.	About respiratory function of the diaphragm
Derrey S. et al. (2006)	Restoration Of Diaphragmatic Function After Diaphragm Reinnervation By Inferior Laryngeal Nerve; Experimental Study In Rabbits	Surgical study
Detroyer A. et al. (1994)	Do Canine Scalene And Sternomastoid Muscles Play A Role In Breathing	No assessment of the diaphragm
Elkins MR. et al. (2005)	Effect Of Body Position On Maximal Expiratory Pressure And Flow In Adults With Cystic Fibrosis	No assessment of the diaphragm
Etnier SA. et al. (2004)	Postural Role Of Lateral Axial Muscles In Developing Bottlenose Dolphins (Tursiops Truncatus)	No assessment of the diaphragm

Fajardo VA. et al. (2016)	Diaphragm Assessment In Mice Overexpressing Phospholamban In Slow-Twitch Type I Muscle Fibers	Medical study
Farley BG. et al. (2000)	Trunk Muscle Activity During The Simultaneous Performance Of Two Motor Tasks	No assessment of the diaphragm
Fauroux B. et al. (1999)	Chest Physiotherapy In Cystic Fibrosis: Improved Tolerance With Nasal Pressure Support Ventilation	About respiratory function of the diaphragm
Ferrari A. et al. (2010)	Severe Scoliosis In Neurodevelopmental Disabilities: Clinical Signs And Therapeutic Proposals	No assessment of the diaphragm
Furukawa Y. et al. (2007)	Effects Of Weight Release On Cardiopulmonary Functions During Treadmill Walking	No assessment of the diaphragm
Galvez-Jimenez N. et al. (2004)	The Perioperative Management Of Parkinson's Disease Revisited	No assessment of the diaphragm
Gandevia SC. et al. (1993)	Respiratory Sensations, Cardiovascular Control, Kinaesthesia And Transcranial Stimulation During Paralysis In Humans	About respiratory function of the diaphragm
Gandevia SC. et al. (2002)	Balancing acts: Respiratory sensations, motor control and human posture.	Review
Glass P. et al. (2001)	Construction Of Westminster Station, London	No assessment of the diaphragm
Goodman BE. et al. (2002)	Teaching Human Cardiovascular And Respiratory Physiology With The Station Method	About respiratory function of the diaphragm
Gosselink R (2003)	Controlled Breathing And Dyspnea In Patients With Chronic Obstructive Pulmonary Disease (COPD)	About respiratory function of the diaphragm
Gronbaek P. et al. (1960)	The activity pattern of the diaphragm and some muscles of the neck an trunk in chronic asthmatics and normal controls – a comparative electromyographic study	No abstract / full tekst available
Habler HJ et al. (1995)	Coordination Of Sympathetic And Respiratory Systems - Neurophysiological Experiments	Medical study
Habler HJ. et al. (1996)	Two Distinct Mechanisms Generate The Respiratory Modulation In Fibre Activity Of The Rat Cervical Sympathetic Trunk	Medical study
Habler HJ. et al. (1997)	Responses Of Distinct Types Of Sympathetic Neuron To Stimulation Of The Superior Laryngeal Nerve In The Cat	Medical study
Hamarneh SR. et al. (2015)	Relationship Between Serum Igf-1 And Skeletal Muscle Igf-1 Mrna Expression To Phosphocreatine Recovery After Exercise In Obese Men With Reduced Gh	No assessment of the diaphragm
Han D. et al. (2011)	The Effect Of Cervical Muscle Exercise On Respiratory Gas In Allergic Rhinitis	No assessment of the diaphragm
Hodges P. (2008)	Transversus Abdominis: A Different View Of The Elephant	No assessment of the diaphragm
Hodges PW. (1999)	Is There A Role For Transversus Abdominis In Lumbo-Pelvic Stability?	No assessment of the diaphragm
Hodges PW. et al. (2001)	In Vivo Measurement Of The Effect Of Intra-Abdominal Pressure On The Human Spine	No postural task of the diaphragm
Hodges PW. et al. (2002)	Coexistence Of Stability And Mobility In Postural Control: Evidence From Postural Compensation For Respiration	About respiratory function of the diaphragm
Hodges PW. et al. (2003)	Experimental Muscle Pain Changes Feedforward Postural Responses Of The Trunk Muscles	No assessment of the diaphragm
Hodges PW. et al. (2007)	Postural And Respiratory Functions Of The Pelvic Floor Muscles	No assessment of the diaphragm
Horecky J. et al. (2009)	Minimally Invasive Surgical Approach For Three-Vessel Occlusion As A Model Of Vascular Dementia In The Rat-Brain Bioenergetics Assay	Surgical study
Horner RL. (2012)	Neural Control Of The Upper Airway: Integrative Physiological Mechanisms And Relevance For Sleep Disordered Breathing	About respiratory function
Hulme JA. et al. (2000)	Research In Geriatric Urinary Incontinence: Pelvic Muscle Force Field	No assessment of the diaphragm
Iscoe S. (2000)	Segmental Responses Of Abdominal Motoneurons In Decerebrate Cats	No assessment of the diaphragm
Iwarsson J. (2001)	Effects Of Inhalatory Abdominal Wall Movement On Vertical Laryngeal Position During Phonation	No assessment of the diaphragm
Jimmenez RF. et al. (1997)	Continuous Wavelet Transform Of Aortic Pressure Oscillations In Anesthetized Dogs: Effects Of 45 Degrees Tilting	No assessment of the diaphragm
Kato S. et al. (2017)	Innovative exercise device for the abdominal trunk muscles: An early validation study.	No assessment of the diaphragm
Kavanau JL. (1996)	Memory, Sleep, And Dynamic Stabilization Of Neural Circuitry: Evolutionary Perspectives	No assessment of the diaphragm
Kita I. et al. (1996)	Cardiorespiratory Changes When Balancing One's Whole Body On One Leg With Eyes Closed	About respiratory function of the diaphragm
Kita I. et al. (1998)	Dynamics Of Human Cardiorespiratory Responses To Standing On One Leg With Eyes Closed	About respiratory function of the diaphragm
Klefbeck B et al. (1996)	The Effect Of Trunk Support On Performance During Arm Ergometry In Patients With Cervical Cord Injuries	No assessment of the diaphragm
Kornegay JN. et al. (2014)	NBD Delivery Improves The Disease Phenotype Of The Golden Retriever Model Of Duchenne Muscular Dystrophyf	Medical study
Krassioukov A. (2009)	Autonomic Function Following Cervical Spinal Cord Injury	About respiratory function of the diaphragm
Kravtsova VV. et al. (2016)	Distinct Alpha 2 Na, K-Atpase Membrane Pools Are Differently Involved In Early Skeletal Muscle Remodeling During	Medical study

	Disuse	
Kraya T. et al. (2015)	Impairment Of Respiratory Function In Late-Onset Distal Myopathy Due To Matr3 Mutation	About respiratory function of the diaphragm
Kriz J. et al. (2016)	Neurorehabilitation Of Sensorimotor Function After Spinal Cord Injury	About respiratory function of the diaphragm
Kucharczuk KL. et al. (1999)	Fine-Scale Transgenic Mapping Of The Myod Core Enhancer: Myod Is Regulated By Distinct But Overlapping Mechanisms In Myotomal And Non-Myotomal Muscle Lineages	No assessment of the diaphragm
Kweon M. et al. (2013)	The Neural Control of Spinal Stability Muscles during Different Respiratory Patterns	About respiratory function of the diaphragm
Lamberg EM. et al. (2005)	Visual Properties Of Objects Affect Manipulative Forces And Respiration Differently	About respiratory function of the diaphragm
Lamberg EM. et al. (2010)	Breath Control During Manual Free-Style Lifting Of A Maximally Tolerated Load	No assessment of the diaphragm
Laudani L. et al. (2013)	Association Between Physical Activity Levels And Physiological Factors Underlying Mobility In Young, Middle-Aged And Older Individuals Living In A City District	No assessment of the diaphragm
Leonhardt M. et al. (2004)	Subdiaphragmatic Vagal Deafferentation Fails To Block The Anorectic Effect Of Hydroxycitrate	Medical study
Lewit K. et al. (2003)	A Case Of Selective Paresis Of The Deep Stabilisation System Due To Boreliosis	No assessment of the diaphragm
Liu B. (2007)	Backpack Load Positioning And Walking Surface Slope Effects On Physiological Responses In Infantry Soldiers	About respiratory function of the diaphragm
Lo C. et al. (2015)	Banding The Right Ventricular Assist Device Outflow Conduit: Is It Really Necessary With Current Devices?	No assessment of the diaphragm
Lopes EA. et al. (2007)	Assessment Of Muscle Shortening And Static Posture In Children With Persistent Asthma	About respiratory function of the diaphragm
Lunardi AC. et al. (2011)	Musculoskeletal Dysfunction And Pain In Adults With Asthma	No assessment of the diaphragm
Maiolo C. et al. (2002)	Body Composition And Pulmonary Function In Obese Type 2 Diabetic Women	About respiratory function of the diaphragm
Maki BE. et al. (1996)	Influence Of Arousal And Attention On The Control Of Postural Sway	About respiratory function of the diaphragm
Massery M. et al. (2013)	Effect Of Airway Control By Glottal Structures On Postural Stability	About respiratory function of the diaphragm
McLaughlin L. et al. (2011)	Breathing Evaluation And Retraining As An Adjunct To Manual Therapy	About respiratory function of the diaphragm
Miyamoto K. et al. (2002)	Fast Magnetic Resonance Imaging Used To Evaluate The Effect Of Abdominal Belts During Contraction Of Trunk Muscles	About respiratory function of the diaphragm
Montes AM. et al. (2016)	Abdominal Muscle Activity During Breathing With And Without Inspiratory And Expiratory Loads In Healthy Subjects	About respiratory function of the diaphragm
Montes AM. et al. (2017)	Abdominal muscle activity during breathing in different postures in COPD "Stage 0" and healthy subjects.	No assessment of the diaphragm
Morais N. et al. (2016)	Posture And Mobility Of The Upper Body Quadrant And Pulmonary Function In COPD: An Exploratory Study	About respiratory function of the diaphragm
Morris JN. (1997)	Walking To Health	No assessment of the diaphragm
Mu L. et al. (2009)	The Human Cricothyroid Muscle: Three Muscle Bellies And Their Innervation Patterns	No assessment of the diaphragm
O'Halloran KD. et al. (1998)	Influence Of Cervical Sympathetic Nerves On Ventilation And Upper Airway Resistance In The Rat	About respiratory function of the diaphragm
Ohlsson, M. et al. (2017)	Sitting position affects performance in cross-country sit-skiing.	No assessment of the diaphragm
Park H. et al. (2015)	The Role Of Visual Feedback In Respiratory Muscle Activation And Pulmonary Function	About respiratory function of the diaphragm
Park JW. et al. (2015)	The Influences Of Position And Forced Respiratory Maneuvers On Spinal Stability Muscles	About respiratory function of the diaphragm
Park RJ. et al. (2012)	Differential Activity Of Regions Of The Psoas Major And Quadratus Lumborum During Submaximal Isometric Trunk Efforts	No assessment of the diaphragm
Pauletto P. et al. (1995)	Smooth Muscle Cell Types At Different Aortic Levels And In Microvasculature Of Rabbits With Renovascular Hypertension	No assessment of the diaphragm
Pederiva F. et al. (2010)	Bronchopulmonary Innervation Defects In Infants And Rats With Congenital Diaphragmatic Hernia	Medical study
Peterson DK. et al. (1994)	Long-Term Intramuscular Electrical Activation Of The Phrenic-Nerve - Efficacy As A Ventilatory Prosthesis	Medical study
Philpot J. et al. (2001)	Neonatal Arthrogryposis And Absent Limb Muscles: A Muscle Developmental Gene Defect?	No assessment of the diaphragm
Pitts T. et al. (2009)	Impact Of Expiratory Muscle Strength Training On Voluntary Cough And Swallow Function In Parkinson Disease	About respiratory function of the diaphragm
Plaszewski M. et al. (2015)	Study Protocol And Overview Of The Literature On Long-Term Health And Quality Of Life Outcomes In Patients Treated In Adolescence For Scoliosis With Therapeutic Exercises	No assessment of the diaphragm
Polese JC. et al. (2013)	Strength Of The Respiratory And Lower Limb Muscles And Functional Capacity In Chronic Stroke Survivors With Different Physical Activity Levels	About respiratory function of the diaphragm
Poussel M. et al. (2014)	Supine Changes In Lung Function Correlate With Chronic Respiratory Failure In Myotonic Dystrophy Patients	About respiratory function of the diaphragm
Prigent H. et al. (2010)	Relation Between Corset Use And Lung Function Postural Variation In Spinal Cord Injury	About respiratory function of the diaphragm
Ragnarsson KT. et al. (2008)	Functional Electrical Stimulation After Spinal Cord Injury: Current Use, Therapeutic Effects And Future Directions	No assessment of the diaphragm
Rassler B. et al. (2000)	Interactions Of Breathing With The Postural Regulation Of The Fingers	No assessment of the diaphragm
Rathinaraj ASL. et al. (2017)	Forced Expiratory Volume in the first second [FEV1] in patients with chronic low back pain.	About respiratory function of the diaphragm

Richardson WH. et al. (2007)	Rattlesnake Envenomation With Neurotoxicity Refractory To Treatment With Crotaline Fab Antivenom	No assessment of the diaphragm
Roberts B. et al. (2013)	Cancer Cachexia Decreases Specific Force And Accelerates Fatigue In Limb Muscle	No assessment of the diaphragm
Robles-Ribeiro PG. et al. (2005)	Relationship Between Peak Expiratory Flow Rate And Shoulders Posture In Healthy Individuals And Moderate To Severe Asthmatic Patients	About respiratory function of the diaphragm
Roig M. et al. (2009)	Falls In Patients With Chronic Obstructive Pulmonary Disease: A Call For Further Research	Review
Sakaguchi T. et al. (1991)	Gastric vagal fibers distribution and acid-secretion induced by portal infusion of d-glucose	No assessment of the diaphragm
Sapsford R. (2004)	Rehabilitation Of Pelvic Floor Muscles Utilizing Trunk Stabilization	No assessment of the diaphragm
Saribeyoglu K. et al. (2007)	Laparoscopy Offers Diagnosis And Treatment In Abdominal Stab Injuries	Surgical study
Savolainen J. et al. (1995)	Fiber Types And Myosin Heavy-Chain Composition In Muscles Of Common Shrew (Sorex-Araneus)	No assessment of the diaphragm
Saywell SA. et al. (2011)	Electrophysiological And Morphological Characterization Of Propriospinal Interneurons In The Thoracic Spinal Cord	No assessment of the diaphragm
Schilling N. et al. (2006)	Sagittal Spine Movements Of Small Therian Mammals During Asymmetrical Gaits	No assessment of the diaphragm
Schomburg ED. et al. (2003)	Rhythmic Phrenic, Intercostal And Sympathetic Activity In Relation To Limb And Trunk Motor Activity In Spinal Cats	Medical study
Schonhofer B. (2005)	Difficult Weaning After Prolongued Medical Ventilation	Review
Sundin L. et al. (2002)	Branchial Innervation	No assessment of the diaphragm
Taillon-Hobson A. et al. (2011)	Voluntary And Automatic Recruitment Of Superficial And Deep Abdominal Muscles In Adults With And Without Cystic Fibrosis	No assessment of the diaphragm
Takizawa D. et al. (2015)	Proton Beam Therapy For A Patient With Large Rhabdomyosarcoma Of The Body Trunk	Medical study
Tantucci C. et al. (1995)	Influence Of Autonomic Neuropathy Of Different Severities On The Hypercapnic Drive To Breathing In Diabetic Patients	About respiratory function of the diaphragm
Tiller NB. et al. (2017)	Effect of cadence on locomotor-respiratory coupling during upper-body exercise.	About respiratory function of the diaphragm
TRIEDMAN, JK. et al., (1993)	Mild hypovolemic stress alters autonomic modulation of heart-rate	No assessment of the diaphragm
Tsao H. et al. (2009)	How Fast Are Feedforward Postural Adjustments Of The Abdominal Muscles?	No assessment of the diaphragm
Urquhart DM. (2005)	Differential Activity Of Regions Of Transversus Abdominis During Trunk Rotation	No assessment of the diaphragm
Valle MS. et al. (2016)	Quantitative Analysis Of Upright Standing In Adults With Late-Onset Pompe Disease	No assessment of the diaphragm
Vandenbroucque G. et al. (1995)	Pulmonary Complication And Peritonitis: The Role Of Respiratory Physiotherapy	Review
Varrato J. et al. (2001)	Postural Change Of Forced Vital Capacity Predicts Some Respiratory Symptoms In Als	About respiratory function of the diaphragm
Villoria A. et al. (2008)	Abdominal Accommodation: A Coordinated Adaptation Of The Abdominal Wall To Its Content	No postural task of the diaphragm
Vogt B. et al. (2016)	Influence Of Torso And Arm Positions On Chest Examinations By Electrical Impedance Tomography	No assessment of the diaphragm
Wang Y. et al. (1996)	3D MR Angiography Of Pulmonary Arteries Using Realtime Navigator Gating And Magnetization Preparation	Medical study
Wang YX. et al. (1998)	Respiratory And Metabolic Functions Of Carbonic Anhydrase In Exercised White Muscle Of Trout	Medical study
Watkins PJ (1998)	The Enigma Of Autonomic Failure In Diabetes	Review
Weyland A. et al. (1993)	Evaluation Of The Image Intensifier-Assisted Technique Of Lumbar Sympathetic Block - Ct Simulation Of A Paravertebral Approach	Surgical study
Wilhelmsen K. et al. (2014)	Examination And Treatment Of Patients With Unilateral Vestibular Damage, With Focus On The Musculoskeletal System: A Case Series	No assessment of the diaphragm
Wind P. et al. (1999)	Anatomy Of The Common Trunk Of The Middle And Left Hepatic Veins: Application To Liver Transplantation	Surgical study
Wu ZX. et al. (2006)	Nerve Growth Factor-Enhanced Airway Responsiveness Involves Substance P In Ferret Intrinsic Airway Neurons	Medical study
Yamada S. et al. (2016)	Decreased Peak Expiratory Flow Associated with Muscle Fiber-Type Switching in Spinal and Bulbar Muscular Atrophy.	About respiratory function of the diaphragm
Yates JS. et al. (1994)	Thalamocortical Projections Activated By Phrenic-Nerve Afferents In The Cat	Medical study
Zordan VB. et al. (2006)	Breathe Easy: Model And Control Of Human Respiration For Computer Animation	About respiratory function of the diaphragm

TABLE 2C: Overview excluded studies and reason of exclusion Smith MD. AND Hodges PW. PubMed and Web Of Science

Source	Title	Reason of exclusion
Smith MD. et al. (2006)	Disorders Of Breathing And Continence Have A Stronger Association With Back Pain Than Obesity And Physical Activity.	No assessment of the diaphragm
Smith MD. et al. (2007)	Postural Response Of The Pelvic Floor And Abdominal Muscles In Women With And Without Incontinence.	No assessment of the diaphragm
Smith MD. et al. (2007)	Postural Activity Of The Pelvic Floor Muscles Is Delayed During Rapid Arm Movements In Women With Stress Urinary Incontinence.	No assessment of the diaphragm
Smith MD. et al. (2008)	How Common Is Back Pain In Women With Gastrointestinal Problems?	No assessment of the diaphragm
Smith MD. et al. (2008)	Is There A Relationship Between Parity, Pregnancy, Back Pain And Incontinence?	No assessment of the diaphragm
Smith MD. et al. (2008)	Is Balance Different In Women With And Without Stress Urinary Incontinence?	No assessment of the diaphragm
Smith MD. et al. (2009)	Do Incontinence, Breathing Difficulties, And Gastrointestinal Symptoms Increase The Risk Of Future Back Pain?	No assessment of the diaphragm
Smith MD. et al. (2014)	The Relationship Between Incontinence, Breathing Disorders, Gastrointestinal Symptoms, And Back Pain In Women: A Longitudinal Cohort Study.	No assessment of the diaphragm
Smith MD. et al. (2016)	Out-Patient Pulmonary Rehabilitation Improves Medial-Lateral Balance In Subjects With Chronic Respiratory Disease: Proof-Of-Concept Study.	No assessment of the diaphragm
Smith MD. et al. (2016)	Balance Recovery Is Compromised And Trunk Muscle Activity Is Increased In Chronic Obstructive Pulmonary Disease.	No assessment of the diaphragm

Quality assessment of included studies in chronological order (n= 42)

Table 3A: Checklist for RCT's (NICE Methodology)

	A1	A2	A3	Risk of bias	B1	B2	B3	Risk of bias	C1	C2	C3	Risk of bias	D1	D2	D3	D4	D5	Risk of bias	Overall
Janssens L. et al. 2014 (16)	U	U	+	U	+	U	U	U	+	+	+	L	-	+	U	U	U	U	+

Table 3B: Checklist for observational studies (STROBE Statement) (1)

	Almeida VP. et al, 2013	Beales DJ. et al, 2010	Bitnar P. et al, 2016	Druz WS. et al, 1982	Gandevia SC. et al, 1990	Griffiths LA. et al, 2012	Hagins M. et al, 2004	Hagins M. et al, 2011	Hamaoui A. et al, 2014
1a	+	-	-	-	-	-	-	+	-
1b	+	+	+	+	+	+	+	+	+
2	+	+	+	-	+	+	+	+	+
3	+	+	-	-	-	+	-	+	+
4	+	+	+	+	+	+	+	+	+
5	-	-	-	-	-	-	-	+	-
6a	+	-	+	+	-	+	+	+	-
6b	N/A	N/A	N/A	N/A	N/A	N/A	N/A	+	N/A
7	+	+	+	+	+	+	+	+	+
8	+	+	+	+	+	+	+	+	+
9	+	-	+	+	+	+	+	+	+
10	+	-	-	-	-	-	+	+	-
11	+	+	+	+	+	+	+	+	+
12a	+	+	+	-	-	+	+	+	-
12b	+	+	+	-	+	+	+	+	+
12c	-	-	-	-	-	-	-	+	+
12d	+	N/A	N/A	N/A	N/A	N/A	N/A	+	N/A
12e	-	-	-	-	+	-	-	-	-
13a	+	-	-	+	+	-	-	+	-
13b	+	+	-	-	-	-	-	+	-
13c	+	-	-	-	-	-	-	-	-
14a	+	+	+	+	-	+	+	+	+
14b	-	+	-	-	-	-	-	-	-
14c	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
15	+	+	+	+	+	+	+	+	+
16a	+	+	+	+	+	+	+	+	+
16b	-	-	-	-	-	-	-	+	-
16c	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
17	-	+	+	-	+	+	+	+	+
18	+	+	+	+	+	+	+	+	+
19	+	+	+	+	-	+	-	-	+
20	+	+	+	+	+	+	+	+	+
21	+	+	+	+	-	+	-	+	+
22	-	+	+	-	-	+	+	-	+

Yes (+), No (-), Unknown/Unclear (U), Not applicable (N/A)

Table 3C: Checklist for observational studies (STROBE Statement) (2)

	Hart N. et al, 2005	Hellyer NJ. et al, 2017	Hodges PW., Butler JE. et al, 1997	Hodges PW., Gandevia SC. et al, 1997	Hodges PW. et al, 2000. *	Hodges PW. et al, 2000	Hodges PW. et al, 2001	Hodges PW. et al, 2003
1a	-	+	-	-	-	-	-	-
1b	+	+	+	+	+	+	+	+
2	-	+	+	+	+	+	+	+
3	+	+	-	-	+	-	-	+
4	+	+	+	+	+	+	+	+
5	-	-	-	-	-	-	-	-
6a	-	+	-	-	-	-	+	-
6b	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	+	+	+	+	+	+	+	-
8	+	+	+	+	+	+	+	+
9	+	+	+	+	-	-	-	-
10	-	-	-	-	+	-	-	-
11	+	+	+	+	+	+	+	+
12a	+	+	-	+	+	+	+	-
12b	+	+	+	+	+	+	+	+
12c	-	-	-	-	-	-	-	-
12d	N/A	+	N/A	N/A	N/A	N/A	N/A	N/A
12e	-	-	-	-	-	-	-	-
13a	-	+	+	-	+	+	+	-
13b	-	-	-	-	-	-	-	-
13c	-	-	-	-	-	-	-	-
14a	+	-	-	+	+	+	+	+
14b	-	+	-	-	-	-	+	-
14c	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
15	+	+	+	+	+	+	+	+
16a	-	+	+	+	+	+	+	+
16b	-	+	-	+	-	-	-	-
16c	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
17	+	+	+	+	+	+	+	+
18	+	+	+	+	+	+	+	+
19	+	+	+	-	-	-	-	+
20	+	+	+	+	+	+	+	+
21	+	+	-	-	+	+	+	+
22	+	-	-	-	-	-	-	+

Yes (+), No (-), Unknown/Unclear (U), Not applicable (N/A). * Title: Activation of the human diaphragm during a repetitive postural task.

Table 3D: Checklist for observational studies (STROBE Statement) (3)

	Hodges PW. et al, 2005	Jandt SR. et al, 2011	Janssens L. et al, 2010	Janssens L. et al, 2013. *	Janssens L. et al, 2013	Kawabata M. et al, 2010	Kawabata M. et al, 2014	Kolar P. et al, 2009	Kolar P. et al, 2010
1a	-	+	+	-	-	-	-	-	-
1b	+	+	+	+	+	+	+	+	+
2	+	+	+	+	+	+	+	+	+
3	-	+	-	+	+	-	+	-	-
4	+	+	+	+	+	+	+	+	+
5	-	+	+	-	-	-	-	-	-
6a	-	+	+	+	+	+	+	-	+
6b	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	+	+	+	+	+	+	+	+	+
8	+	+	+	+	+	+	+	+	+
9	+	+	+	+	+	+	+	+	+
10	-	+	+	-	-	-	-	-	-
11	+	+	+	+	+	+	+	+	+
12a	-	-	+	+	+	+	-	+	+
12b	+	+	+	+	+	+	+	+	+
12c	+	-	-	+	+	-	-	-	-
12d	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12e	-	-	-	-	-	-	-	-	-
13a	+	+	+	+	+	-	-	-	+
13b	+	+	-	+	+	-	-	-	-
13c	-	-	-	-	-	-	-	-	-
14a	+	+	+	+	+	+	+	+	+
14b	+	+	-	+	+	-	-	+	-
14c	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
15	+	+	+	+	+	+	+	+	+
16a	+	+	+	+	+	+	+	+	+
16b	+	-	+	-	-	+	+	-	+
16c	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
17	+	+	+	-	+	+	+	+	+
18	+	+	+	+	+	+	+	+	+
19	+	+	+	+	-	-	-	-	+
20	+	+	+	+	+	+	+	+	+
21	+	+	+	+	+	-	+	+	+
22	-	-	+	-	+	-	+	-	+

Yes (+), No (-), Unknown/Unclear (U), Not applicable (N/A). * Title: Greater diaphragm fatigability in individuals with recurrent low back pain.

Table 3E: Checklist for observational studies (STROBE Statement) (4)

	Kolar P. et al, 2012	O'Sullivan PB. et al, 2002	Priori R. et al, 2013	Roussel N. et al, 2009	Segizbaeva MO. et al, 2013	Shirley D. et al, 2003	Sinderby C. et al, 1992	Smith MD. et al, 2010	Takazakura R. et al, 2004
1a	+	-	-	+	-	-	-	-	-
1b	+	+	+	+	+	+	+	+	+
2	+	+	+	+	+	+	+	+	+
3	+	+	+	+	-	-	-	+	-
4	+	+	+	+	+	+	+	+	+
5	+	-	-	+	-	-	-	-	-
6a	+	+	+	+	-	-	+	+	+
6b	N/A	+	N/A	N/A	N/A	N/A	N/A	+	N/A
7	+	+	+	+	+	+	+	+	+
8	+	+	+	+	+	+	+	+	+
9	+	+	+	+	+	+	+	+	-
10	-	+	-	+	-	-	-	+	-
11	+	+	+	-	+	+	+	+	+
12a	+	+	+	+	-	+	-	+	-
12b	+	+	+	+	-	+	+	+	-
12c	-	-	+	-	-	+	-	-	+
12d	N/A	N/A	N/A	+	N/A	N/A	N/A	N/A	N/A
12e	-	-	-	-	-	-	-	-	-
13a	+	-	+	-	+	-	+	-	+
13b	-	-	-	-	-	-	-	+	+
13c	-	-	-	-	-	-	-	-	-
14a	+	+	+	+	+	+	+	+	+
14b	-	-	+	-	-	-	-	+	+
14c	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
15	+	+	+	+	+	+	+	+	+
16a	+	+	+	+	+	+	+	+	+
16b	+	-	+	-	-	+	+	-	+
16c	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
17	+	+	+	+	-	+	+	+	-
18	+	+	+	+	+	+	+	+	+
19	+	+	+	+	-	+	+	+	+
20	+	+	+	+	+	+	+	+	+
21	+	+	+	+	+	+	+	+	-
22	-	-	+	+	+	-	-	+	-

Yes (+), No (-), Unknown/Unclear (U), Not applicable (N/A)

Table 3F: Checklist for observational studies (STROBE Statement) (5)

	Terada M. et al, 2016	Uchida M. et al, 2010	Uga M. et al, 2010. *	Uga M. et al, 2010	Vostatek P. et al, 2013	Wüthrich TU. et al, 2014 (18)
1a	-	-	-	-	-	-
1b	+	+	+	+	+	+
2	+	+	-	+	+	+
3	+	-	-	-	-	+
4	+	+	+	+	+	+
5	+	-	-	-	-	-
6a	+	-	-	-	+	+
6b	N/A	N/A	N/A	N/A	N/A	N/A
7	+	-	-	+	+	+
8	+	+	-	-	+	+
9	+	+	-	+	+	+
10	+	+	-	-	-	-
11	+	+	+	+	+	+
12a	+	-	-	-	+	+
12b	-	+	-	+	+	+
12c	-	-	-	-	+	+
12d	N/A	N/A	N/A	N/A	N/A	N/A
12e	-	-	-	-	-	-
13a	-	-	+	+	-	-
13b	-	-	-	+	+	+
13c	-	-	-	-	-	-
14a	+	+	-	-	+	+
14b	-	-	-	+	+	-
14c	N/A	N/A	N/A	N/A	N/A	N/A
15	+	+	+	+	+	+
16a	+	+	-	+	+	+
16b	+	-	+	+	+	+
16c	N/A	N/A	N/A	N/A	N/A	N/A
17	-	+	-	+	+	+
18	+	+	+	+	+	+
19	+	+	-	-	+	+
20	+	+	+	+	+	+
21	+	+	-	-	+	+
22	+	-	-	-	+	+

Yes (+), No (-), Unknown/Unclear (U), Not applicable (N/A). * Title: The diaphragmatic activities during trunk movements.

TABLE 4: Strengths and weaknesses analysis of the included studies in alphabetical order (n= 42)

Author	Strengths	Weaknesses
Almeida VP. et al. 2013	- Reasons of exclusion well reported - Ratio men/women in agreement with reports of higher prevalence of asthma among adult females	- The lack of a control group - The cross-sectional design - Small sample size
Beales, DJ. et al., 2010	- Duplicate trials for repeatability analyses were added to the protocol after the first four subjects had been recruited and data collected. Consistency was very good for all variables except baseline shift of iap and itp that were poor and fair, respectively.	- Surface electrodes will also record activity from the overlying synergistic intercostal muscles. Electrode placing for m. Obliquus internus will also pick up EMG from the synergistic transversus abdominis - Use of surface EMG could oversimplify the motor control processes that occurred - A fixed value for inspiratory resistance was used, thus individual factors such as physical fitness levels and inspiratory muscle strength could have confounded the results - There may be not sufficient power to fully inform the intricacies of the motor control patterns displayed
Bitnar, P. et al., 2016	- The member with the most clinical experience performed all measurements. - It was assured that the conditions under which testing was conducted were uniform and the same catheter was used for all assessments - Probably the most unique part of this study is the confirmation of intra-abdominal pressure influence on upper esophageal sphincter pressure. - High-resolution manometry appears to be an appropriate method to evaluate this combined diaphragmatic function.	- Gastrooesophageal reflux disease (GERD) was carefully clinically ascertained and presence of common associated diseases was ruled out, but it is still possible that some other physiological process or condition were present. - All patients with GERD involved complained of chronic pain but there was no specific relationship between these symptoms. - No direct diaphragm measurements were done. - Relatively small sample, potentially compromising explanatory power. - Most studies using high-resolution manometry are conducted based on measurements in supine, whereas deglutition but also other movements and activities occur mostly in the upright position
Druz WS. et al., 1982	- Observations were repeatable - The esophageal electrode catheter was not anchored with a gastric balloon, but the experiments of önal and associates demonstrated that catheters of the type used in this study record the diaphragmatic EMG adequately and that stabilization with an inflated gastric balloon does not improve the reproducibility of diaphragmatic EMG data. The esophageal recordings of diaphragm EMG were accepted as valid. - A tilt table was used for supine and standing studies, the table being tilted 80° head-up for the latter. This resulted in greater stability of magnetometer tracings because spinal attitude and shoulder and trunk configuration varied less.	- In 2 patients with COPD in whom the delta diaphragm EMG did not increase on assuming the erect positions, the authors could not as easily exclude artifacts. - In 4 of the normal subjects and 3 of the patients, the sequence of body position was reversed, supine observations being repeated after standing and sitting observations and sitting observations being made before standing observations. - Because of poor contrasts of oscillographic records, they were redrawn for figures.
Gandevia SC. et al., 1990	- Motor cortical stimulation at the vertex produces a powerful and rapidly conducting excitatory input to motoneurons of mid-line and leg muscles - Loud verbal encouragement and biofeedback were always provided which caused well motivated subjects - During repeated brief maximal voluntary efforts in all subjects there were some trials in which the twitch force was completely occluded, indicating that the diaphragm was being driven maximally. This was confirmed by averaging several 'successful' trials, a technique which increases the sensitivity of the test - The present neurophysiological study of the activation of the diaphragm and its synergists during different maximal tasks is the first to use motorcortical stimulation as a test of maximal voluntary drive to muscles acting in-series	- No specific mentioning of limitations in discussion - Any major technical fault was excluded which may have meant that superimposed force increments were 'missed' during inspiratory efforts, and have shown a number of pressure recordings at high gain
Griffiths LA. et al., 2012	- The standardization of the starting lung volume by initiating each manoeuvre from the upright posture (inhaling or exhaling before adopting the test posture) would have minimized the influence of posture upon the measured pressures. However,	- It is likely that if starting lung volume had not been standardized, that posture would have exerted a more potent influence upon respiratory mouth pressures than was observed

	this was performed in order to minimize the effect of starting lung volumes upon the measured pressures, thereby isolating any effects of postural co-contraction of trunk muscles - Each manoeuvre was performed a minimum of three times to maximize reliability	- The two positions are not directly comparable, but the modified position allowed for an uncontaminated assessment of the postural role of respiratory muscles in this position - The results of this study are not directly applicable to the catch position, and probably represent a best-case scenario in terms of the detrimental influence of this posture upon respiratory function in this position - There may have been a degree of error in the positioning of the participants
Hagins, M. et al., 2004	- Loads were normalized for each subject to 70% and 35% of the average of two trials of maximum isometric trunk extensor exertion in an upright posture. - To capture natural breathing patterns without bias, subjects were not fully informed of the study's focus on natural breath control, and all trials using this breathing method were performed first.	- No specific mentioning of limitations in discussion. - The measurement of timing of intra-abdominal pressure used in the present study based on a single peak magnitude value may not be optimal
Hagins, M. et al., 2011	- In addition to the primary purpose, this study explored whether age and gender modified breath control during a lifting task, no study has yet examined the influence of age or gender on breath control during lifting tasks. - To minimize the possibility of participants consciously controlling their breath during the lift, they were not informed of the specific purpose of the experiment. - The Oswestry Low Back Pain Disability and The Baecke Physical Activity questionnaire has been shown to be reliable and valid. - Six participants returned for a second day of identical testing to determine reliability, this indicated that the measure of %Vital Capacity was highly reliable for heavy loads and moderately reliable for light loads, although the 95% CIS are very wide. - To eliminate bias associated with the initial cue to begin lifting and to provide for 2 complete, independent lifting sequences that included both lift-off and placement of the load, only data from trials 2 and 4 of each series were included. - This study provides the first evidence that natural breath control during a lifting task differs significantly in individuals with low back pain compared to age-matched and gender-matched healthy controls.	- No specific mentioning of limitations in discussion. - The cross-sectional design of this study renders it impossible to determine whether the breath differences in the low back pain group are causative or compensatory.
Hamaoui A. et al. 2014	- Results are consistent with other studies - Measurements were taken by one investigator with a lot of experience: no intersubject heterogeneity - Limitation of technical error - Strong evidence that the diaphragm has a specific, posture-dependent impact on body balance	- Small sample size - Failed to use a phrenic nerve stimulation device that would avoid contact between the investigator and the subject and aid symmetrical stimulation, because of that there might have been electrode displacement - Diaphragm contraction by phrenic nerve stimulation, therefore there is no generalizability for physiological breathing
Hart N. et al., 2005	- Data are in consistent with the observations of studies that have found an improvement in lung volume when the abdomen is bound:	- Diaphragm moves craniocaudal and outward, therefore the points measured at end inspiration were not exactly the same points measured at end expiration - The entire thorax could not be imaged due to limited size - The fall in abdominal compliance with application of the girdle could influence the observed increase in diaphragm performance
Hellyer NJ. et al., 2017	- Gender was compared; there was the same amount of women than men in the sample size. - Sample size was calculated on the base of statistical power.	- The diaphragm was monitored in healthy subjects, not in those with respiratory or low back dysfunction and therefore it is not known how well the results would generalize to patient populations or whether the measurement will be sufficiently sensitive to detect impairments or changes in diaphragm function. - Locations, dates, periods of recruitment and data collection were not described.
Hodges PW. et al., 1997	- The stimulus to move the arm occurred at a random point during the respiratory cycle. To ensure the reaction time was as rapid as possible, the subject was given an audible warning at a random period prior to the stimulus to move. - Trials were rejected on-line if the subject moved before the visual stimulus or failed to respond to it within 400ms. Fewer than 5% of trials were rejected	- The monopolar needle electrode used in this study was selective. This was necessary to minimize cross-talk from adjacent muscles but may have resulted in a failure to detect EMG from the motorunits with the earliest onset - Due to the relatively slow sampling rate of the ultrasound images (28 Hz) the exact time of onset of this change is imprecise for single trials

	- This study provides the first direct evidence that the diaphragm may contribute to the postural control of the human trunk in addition to its role in respiration	
Hodges PW. et al., 1997	- After a loaded inspiration, the EMG activity of transversal abdominal muscle and internal oblique muscle increased during the expiratory phase. Subjects were unaware of possible respiratory responses to loading. - Five practice movements were performed in each condition, with feedback from the experimenters, to ensure consistency of response.	- No specific mentioning of limitations in discussion. - The absolute reaction time for deltoid and the abdominal muscles varied between trials within each condition, and this may obscure any changes in timing of the abdominal muscles relative to the arm movements in the different respiratory phases and different experimental conditions.
Hodges PW. et al., 2000	- Data were normalized - Power spectral densities of the autocorrelations of the EMG, pressure, and movement signals were calculated to identify the frequency of EMG bursts and the frequency of shoulder and rib cage motion. To remove any nonstationarity from the data due to low-frequency drift, and to remove any movement artifact, the EMG data were high-pass filtered at 100 Hz and then rectified and low-pass filtered at 30 Hz - Analysis of the filtered and rectified EMG signal by using the “runs” test indicated that the data satisfied the conditions of stationarity. An additional factor that supports the validity of this analysis is that many of the findings were confirmed by analysis of data averaged with the onset of the movement used as the trigger	- No specific mentioning of limitations in discussion - Although there were small changes in airflow with each repetition of shoulder movement, it was not possible to determine whether this was due to actual changes in airflow or movement of the mouthpiece
Hodges PW. et al., 2000	- Data were normalized - To remove any nonstationarity from the data due to low-frequency drift, and to remove any movement artifact, the EMG data were high-pass filtered at 100 Hz and then rectified and low-pass filtered at 30 Hz - Analysis of the filtered and rectified EMG signal using a runs test on consecutive 1s data intervals indicated that the data satisfied the conditions of stationarity. An additional factor that supports the validity of this analysis is that many of the findings were confirmed by analysis of data averaged with the onset of the movement used as the trigger	- No specific mentioning of limitations in discussion - Small sample size - The signal of ribcage motion measured with the inductance plethysmograph was affected to a small extent by movement of the upper limb. It was impossible to determine whether this was due to artifact or to real changes in volume of the thorax - With the selective multi-unit recordings from the costal diaphragm it was difficult to identify accurately the temporal characteristics of the burst of diaphragm EMG activity from single movements of the upper limb
Hodges PW. et al., 2001	- Data were normalized - Power spectral densities of the autocorrelations of the EMG and movement signals were calculated to identify the frequency of EMG bursts, and the frequency of shoulder and rib cage motion. To remove any non-stationarity from the data due to low-frequency drift, and to remove any movement artefact, the EMG data were high-pass filtered at 100 Hz, and then rectified and low-pass filtered at 30 Hz	- No specific mentioning of limitations in discussion
Hodges PW. et al., 2003	- Results of this study provide the first in vivo evidence that raised IAP and contraction of the diaphragm and transversus abdominis increase intervertebral stiffness	- In this study, the displacement was induced by caudal and rostral displacement of the L4 vertebra. This measure is a less sensitive measure of stiffness of a single intervertebral segment as it may be influenced by other factors such as the stiffness at segments above and below the level of force application. Thus, the displacement did not represent a functional motion and emphasis was placed on the changes in intervertebral kinematics - Another issue is whether the pig is an adequate model of the human spine. Several authors have compared the anatomy of human and quadruped spines and confirmed that they are comparable with few exceptions
Hodges PW. et al., 2005	- Measurement of postero-anterior stiffness in this manner has good test–retest reliability and is accurate within 1% for measurement of stiffness of an elastic beam	- A limited number of subjects participated in the present study due to the discomfort associated with strong tetanic electrical stimulation and the percutaneous stimulation of the phrenic nerves - The measure of posteroanterior stiffness of the spine is a composite measure and is influenced by stiffness of the entire spine and its supporting structures - Although the data indicate that posteroanterior stiffness of the spine is increased

		by the increase in IAP, it was not possible to quantify its contribution to overall stability of the spine; this requires further investigation.
Jandt SR. et al., 2011	- The findings of this study are in agreement with the reports by Hodges et al. (2001) and Hart et al. (2005)	- Small sample size - Limited number of severely affected people with stroke - Likely effect of learning during the evaluation of MIP and MEP - Possible leak from the nozzle in patients with stroke who presented facial weakness, not maintaining a good oral seal
Janssens L. et al. 2014	- Random assignment to intervention group - control group - Use of 3 different questionnaires to objectify pain - Findings can be useful in rehabilitation of low back pain patients, but also in prevention of low back pain in people with breathing problems	- No long term follow up - No blinding used
Janssens L. et al., 2010	- The results are in agreement with a previous finding where differences in postural control could only be found when the task involved increased complexity - This evaluation of inspiratory muscle force seems to be the only noninvasive test to securely assess inspiratory muscle force	- The study failed to verify the presence of inspiratory muscle force following the loaded breathing task - Results cannot be generalized to a more typical population with low back pain
Janssens L. et al., 2013	- Information about diaphragm fatigue as a possible mechanism in recurrent non-specific low back pain, which still is a large gray area - Gives a potential explanation for the relationship between low back pain and respiratory disorders	- Small sample size - Invasive nature of the protocol
Janssens L. et al., 2013	- The first study to evaluate the underlying proprioceptive changes in balance control in individuals with COPD	- Further research needed for assessment of the relation with fall incidence and to evaluate proprioceptive strategies during dynamic postural tasks
Kawabata M. et al. 2014	- Results were consistent with other studies - Inclusion of patients without any confounders	- Small sample size - Did not provide direct evidence regarding lumbar stability in the present study - No direct measurement of the muscles surrounding the abdominopelvic cavity
Kawabata, M. et al., 2010	- The lifting effort values were normalized by the maximal lifting effort, inspiratory volume and expiratory volume were normalized by the tidal volume and intra-abdominal pressure development was normalized by the maximal intra-abdominal pressure during vasalva maneuvers. - The vision of each subject was obstructed so as not to bias their intra-abdominal pressure and respiratory behavior	- No specific mentioning of limitations in discussion. - The previous study demonstrated a significant increase in the natural inspiratory volume up to 130% of tidal volume with lifting of 25% of body weight, although it is impossible to compare these results directly because of different relative efforts for body weight or maximal lifting strengths in the present study.
Kolar P. et al., 2009	- First study showing the voluntary movements of the diaphragm during the respiratory controlled breath hold - Clinical evidence of this study shows similar experiences than other studies	- No specific mentioning of limitations in discussion - Unequal sample size with 6 males and 10 females
Kolar P. et al., 2010	- It's demonstrated that changes in diaphragm excursion and tidal volumes are well correlated for all three experimental conditions - Findings are in agreement with Hodges et al. (2000)	- No imaging of the whole rib cage, just of the diaphragmatic excursion - Each participant has a different subjective ability to balance external pressure and/or resistance - No detection of previously reported finding of asymmetric excursions between hemidiaphragms - Intra-abdominal mass also has an influence on diaphragm excursion, especially in cases of central obesity, therefore the BMI of the participants fell in the normal range - There is a possibility of rib cage distortion during the experimental conditions; this can be changed by passive stretch of the abdominal muscles. This was not considered.
Kolar P. et al., 2012	- The statistical method is adjusted to the groups not being the same - The results provide additional evidence for altered breathing patterns during strenuous and nonstrenuous activity in individuals with low back pain - No research to date has been conducted in which diaphragm dynamics would be visualized in relation to postural tasks and low back pain	- A convenience sample was used, the patient and control groups differed in size and some demographic characteristics - Only an isolated analysis of the diaphragm was performed instead of imaging of the whole rib cage - Force and direction were not formally assessed, although external pressure to

		generate grade 4 force was applied by the same clinician and standardized requirements of current MRI methodology: exclusion of the possibility that the resistance varied across the subjects is not possible - Intra-abdominal pressure was not measured directly - This research did not include any measurement of diaphragm movement
O'Sullivan PB. et al., 2002	- A test–retest repeatability study for all measures was performed on five of the participants from the comparison group to establish the reliability of the measures. There was low variability in the measurement approach. - In this study they use the ASLR to examine the form and force closure mechanism of the sacroiliac joint. This maneuver has been advocated as a reliable test for the quality of load transfer through the lumbo-pelvic region	- The values measured during tidal breathing of the subject at rest were small and a fixed anatomic reference point from which to measure diaphragmatic motion was absent.
Priori R. et al., 2013	- First time that effects of posture on thoracoabdominal asynchrony in COPD have been studied by both opto-electronic plethysmography and ultrasound, this provides a more complete analysis of the relationship between movement of the lower rib cage and the zone of apposition in COPD patients - Use of a control group to compare results	- The pressure signals could not be obtained simultaneously because of signal degradation when supine, and increased patient discomfort - Intervention group and control group do not match
Roussel N. et al., 2009	- The inter-observer reliability of the assessment is generally fair to moderate, therefore all subjects were examined by the same observer - Examiner completely blinded	- No reliability assessment was made by the investigator for the assessment of the breathing pattern - Only manual palpation and visual inspection were used to assess the breathing patterns, which is subjective
Segizbaeva MO. et al., 2013	- The subjects were divided into male and female groups to exclude the effects of these factors, to standardize conditions, to evaluate exclusively the effect of postural changes on MIP	- Higher values can only be achieved after specific muscle coordination training
Shirley D. et al., 2003	- The device used for measurement of postero-anterior stiffness (a strain gauge and linear potentiometer) has good test-retest reliability and is highly accurate. - Although there has been some investigation of the effects of respiration on spinal stiffness, this study is the first to compare the stiffness response of a variety of respiratory efforts, including both inspiration and expiration.	- Noninvasive measurement of spinal stiffness cannot provide an ideal measure of intersegmental stiffness and is affected by the stiffness at segments distant from the site of application of the postero-anterior force.
Sinderby C. et al., 1992	- The statistics used consider the sample size in the analysis	- The number of patients available was limited. The experiments were not altogether effortless for the investigators and not very convenient for the patients, who were therefore difficult to recruit.
Smith MD. et al., 2010	- This finding, that the deficit in balance involves mediolateral rather than anteroposterior control, is important because mediolateral control is more dependent on trunk movement due to poor efficiency of the ankle muscles to control balance in this direction. - Exercise dose was matched between pairs of subjects with and without COPD who were matched for age and gender. - Upper limb exercise was chosen over lower limb exercise to remove the possible effects of lower limb muscle fatigue on balance.	- Hyperinflation was not measured in this study, but may have had an effect on postural control. - Subjects rated breathlessness on the subjective modified borg-scale. - As measures were quantified as angular change rather than linear translation, the exact placement of the inclinometer would have little effect on the accuracy of the data.
Takazakura R. et al., 2004	- The shape of the diaphragm is changed three-dimensionally during respiration. With MRI it is possible to estimate a particular portion of the diaphragm at an arbitrary plane without ionizing radiation - With MRI thoracic motion is not hindered, which guarantees more natural and physiological information of the diaphragm	- Due to the limited length of the coil, it was not possible to encompass the whole lung, especially the apical region - Due to a complex craniocaudal and outward movement of the diaphragm, the points measured at end inspiration were not exactly the same points measured at end expiration in this study
Terada M. et al., 2016	- This study may provide clinicians valuable information for identifying relevant impairments on which to focus during interventions for chronic ankle instability. - The investigator responsible for measuring diaphragm contractility was blinded to group membership.	- The cross-sectional retrospective design makes it difficult to determine whether reduced left hemidiaphragm contractility observed in the chronic ankle instability group is due to the pathology or if the alteration existed before injury. - There was no control of breathing volume using a spirometer. It is possible that

	- Evaluation of diaphragm thickness and contractility using b-mode ultrasound has been demonstrated to be valid and reliable. - We did conduct an exploratory correlation analysis between diaphragm measures and demographic characteristics and physical activity levels, finding non-significant weak associations between these variables.	differences in respiratory volume during the quiet breathing among participants in this current study influence the observations. - Although there were no differences in demographic characteristics and physical activity levels between the chronic ankle instability and the control groups, it is still possible that these factors had some effects on our findings. - The structure and the contractility of the diaphragm were assessed in the supine position; this may not adequately reflect neuromuscular function during a functional task. - Although it was verified that all included limbs did have chronic ankle instability, there was no documentation of whether the included patients with bilateral lateral ankle sprain history had bilateral chronic ankle instability. Unilateral and bilateral chronic ankle instability may have had different outcomes.
Uchida M. et al., 2010	- Measurements were started after the subjects became accustomed to the measurement conditions. - The subjects drew cards in advance to randomize the sequence of measurements and eliminate effects any sequence. - A 2-minute rest was provided before and after each measurement to prevent the effects of respiratory muscle fatigue.	- Because measurements of functional residual capacity (FRC) were considered difficult for the present study, we measured expiratory reserve volume as an indicator of relative changes in FRC. - Healthy subjects were used, but greater decreases in ventilation may be observed in elderly patients and other cases in whom the respiratory function becomes limited due to degeneration.
Uga M. et al., 2010	- Diaphragm and trunk muscle EMG was observed during voluntary movements to gain information essential to know how the centers for the voluntary movements, controlling posture and respiration coordinately, control the diaphragm and trunk muscles using various afferent feedbacks	- Study in only two cats - No specific mentioning of limitations in discussion
Uga M. et al., 2010	- Suggestion that the reaching movements and the standing-up movements may have some different control mechanisms from central nervous systems - Suggestion that the diaphragm may receive an input from the central nervous system in order to adjust lung volume changes during postural changes - There was a clear modulation of the diaphragmatic activity during voluntary trunk movements	- Study in only 4 cats - Diaphragm recordings were limited to the costal portions, although previous studies have shown that larger increases in activity occur in the crural than in the costal diaphragm during nose-up tilts from a supine position
Vostatek P. et al., 2013	- A technique for assessing respiration properties is proposed - The movement of the diaphragm is separated, which is not linked with respiration	- There are limitations of the harmonic model, a more complex model needs to be created
Whüthrich T. et al. 2013	- Constant lung volumes before application of magnetic stimulations are crucial to achieve reproducible twitch measurements, this study has closely monitored them so it is unlikely that the lung volumes have biased the outcomes	- No assessment of EMG responses to magnetic stimulation for inspiratory muscles, but this could lead to an overestimation of contractile fatigue - Only experienced endurance athletes so transfer in other population is difficult

TABLE 5: Data-extraction of included studies in alphabetical order (n= 42)

Authors	Population	Aim of the study	Description of the measurements methods	Results
Almeida VP. et al. 2013	50 individuals with asthma	Compare posture, balance, functional capacity and quality of life according to severity of disease (group A: FEV1>74% predicted, group B: FEV1<74% predicted).	- Respiratory muscle strength: computerized pulmonary function testing systems - Stabilometry: analysis of static postural balance on force platform	- MIP + MEP were lower in group B - Maximal mediolateral velocity and displacement were significantly greater in group B compared to A - In individuals with asthma, pulmonary function is associated with balance control in mediolateral direction
Beales, DJ. et al., 2010	14 pain-free females	Investigate how pain-free subjects coordinate motor control during an ASLR when this task is complicated by the addition of a respiratory challenge	- Trunk muscle activation: EMG - IAP and intra-thoracic pressure by nasogastric catheter	- Activation of oblique internus was greater on the side of the leg lift during ASLR + inspiratory resistance - The increase of motor activity was associated with greater IAP baseline shift when lifting the leg during ASLR + IR
Bitnar, P. et al., 2016	58 patients with gastro-esophageal reflux disease	Determine the relation between posturally increased IAP and lower/upper esophageal sphincter pressure changes in patients with gastro-esophageal reflux disease, during bilateral leg raise	- Pressure changes in lower and upper esophageal sphincter by high resolution manometry	- A significant increase in both lower and upper esophageal sphincter pressure - Patients with initially higher pressure in lower and upper esophageal sphincter exhibited a greater pressure increase during leg raise
Druz WS. et al., 1982	8 normal subjects 6 patients with severe COPD	Assess EMG measurements of respiratory muscles together with measurements of thoraco abdominal motion and gastric, esophageal and transdiaphragmatic pressures in patients with severe chronic obstructive pulmonary disease	- Gastro-esophageal catheter: EMG measurements of the diaphragm and transdiaphragmatic pressure	- Normal subjects: Pdi (transdiaphragmatic pressure) was maintained in all 4 postures - COPD: Pdi decreased during erect sitting and standing - Standing and erect sitting: all healthy subjects and 4/6 COPD patients showed increases in Edi (EMG diaphragm) - 2/6 COPD Edi did not increase in the erect postures: this reflex which normally compensates for reduced diaphragmatic efficiency is not working
Gandevia SC. et al., 1990	7 subjects	Assess the degree of activation of the diaphragm, intercostal-accessory muscles and abdominal muscle during postural tasks and respiratory maneuvers	- Bilateral phrenic nerve stimulation - Motor cortex stimulation - Quantitative EMG of diaphragm, trunk muscles and abdominal muscles - Measurement of transdiaphragmatic pressure and diaphragmatic EMG with a multi-lumen gastro-esophageal catheter	- Bilateral phrenic nerve stimuli: - Average change in transdiaphragmatic pressure during relaxation - Peak voluntary diaphragmatic pressure was about 30% less for inspiratory than expulsive maneuvers - Transcranial activation: increment in abdominal pressure during maximal voluntary expulsive efforts (abdominal muscles fail to generate full contractile force) - Motor cortical stimulation during weak inspiratory efforts: small reduction of esophageal pressure - EMG activity of abdominal muscles and intercostal muscles was greater during trunk flexion than during maximal expulsive efforts.
Griffiths LA. et al., 2012	11 male and 5 female participants	Assess the influence of the postural role of the trunk muscles upon pressure and flow generating capacity, by	- Maximal inspiratory and expiratory mouth pressure maneuvers as surrogates of inspiratory and expiratory muscle strength, measured by a portable handheld mouth	- Respiratory mouth pressures are lower with recumbency, with a decrease in PEmax in unsupported recumbent postures

		measuring maximal respiratory pressures, flows and volumes in various seated postures relevant to rowing	pressure meter - Rowing-related postures: 3 phases (catch, sitting upright, finish) measured by a goniometer for the hip/trunk angle	
Hagins, M. et al., 2004	11 asymptomatic subjects	Examine the effects of breath control on magnitude and timing of IAP during dynamic lifting	- IAP measured using a microtip pressure transducer (in the stomach)	- There was a significant effect of breath control and load, but not of posture, on intra-abdominal pressure magnitude - The inhalation form of breath control produced significantly greater peak IAP than all other forms of breath control
Hagins, M. et al., 2011	30 subjects without low back pain, 32 subjects with chronic mechanical low back pain	Determine if, during a whole-body lifting task, individuals with low back pain breathe differently than age- matched controls	- Pressure sensors on the floor and platform	- Individuals with LBP performed the lifting task with more volume in their lungs than healthy peers - With increasing age, participants with LBP increased inspired volume and participants without LBP decreased inspired volume
Hamaoui A. et al. 2014	8 men, 4 women without any neurological, musculoskeletal or respiratory disease	Study the postural disturbances caused by isolated contractions (unilateral, bilateral and caused by sniff maneuvers) of the diaphragm	- Force plate to measure the centre of gravity - Thoraco abdominal sensor belts to measure changes in rib cage and abdominal circumference - Diaphragm electromyograms - Phrenic nerve stimulation by handheld monopolar electrodes	- Seated: bilateral phrenic stimulation and sniff maneuvers: expansion of the abdomen, associated with a forward peak of CG acceleration - Standing: Centre of gravity peak was reversed and directed backward - Unilateral phrenic stimulation: additional medial-lateral acceleration of centre of gravity, directed to non-active side while seated, to opposite side while standing - Isolated diaphragmatic contractions: constant disturbing pattern for a given posture, with opposite effects between standing and seated postures - Lateral component induced by unilateral diaphragm contractions could be relevant in patients with hemidiaphragm paralysis
Hart N. et al., 2005	10 subjects with SCI	Assess the effect of custom girdles in patients with spinal cord injury (SCI), with both trunk and abdominal support, on the sensation of respiratory effort, pulmonary function, diaphragmatic load and diaphragm strength in patients with SCI during spontaneous breathing while seated	- Transdiaphragmatic pressure measurement	- A decrease in dynamic abdominal compliance + an increase in diaphragm pressure
Hellyer NJ. et al., 2017	24 Healthy subjects (12 male and 12 female).	Whether diaphragm thickness measurements with US differ among 3 different body postures in healthy subjects.	- Diaphragm thickness was assessed in via B-mode ultrasound imaging in supine, seated, and standing postures.	- At end expiratory lung volume, diaphragm thickness was greater in the seated and standing than in the supine position, approximately 30% or 0.7 mm ($p < .001$) seated and 0.7 mm ($p < .001$) standing.
Hodges PW. et al., 1997	5 subjects	Assess the response of the diaphragm to the postural perturbation produced by rapid flexion of the shoulder to a visual stimulus in standing subjects	- Gastric, esophageal and transdiaphragmatic pressure - Intramuscular and esophageal recordings of EMG in the diaphragm - Dynamic changes in the length of the diaphragm measured with US	- Anticipatory EMG contraction of the costal and crural diaphragm: 20ms before the onset of deltoid EMG - Gastric and transdiaphragmatic pressures increased in association with the rapid arm flexion - US revealed that the costal diaphragm shortened and then lengthened progressively during the increase in transdiaphragmatic pressure

Hodges PW. et al., 1997	5 volunteer subjects	Evaluate the influence of respiratory activity of the abdominal muscles on their reaction time in a postural task	- EMG onset of the abdominal muscles and deltoid	- During quiet breathing: the latency between activation of the abdominal muscles and deltoid was not influenced by the respiratory cycle - When respiratory activity of the abdominal muscles increased, the EMG onset of transversus abdominis and internal oblique was significantly earlier for movements relative to deltoid, beginning in expiration, compared with inspiration - The onset of transversus abdominis was delayed when movement was performed during a static expulsive effort, compared with quiet respiration - Changes occur in early anticipatory contraction of transversus abdominis during respiratory tasks
Hodges PW. et al., 2000	EMG: 7 male subjects 6 of them: pressure recordings Changes in respiratory pattern: 10 subjects 3 subjects in both	Investigate the mechanical output of the components of diaphragm activity	- EMG: costal diaphragm, abdominal and erector spinae muscle activity IAP (Pga and Poes), ITP and TDP by pressure transducers - Motions of the rib cage, abdomen and arm by potentiometer	- During limb movement: diaphragm and transversus abdominis were tonically active with added phasic modulation - Activity of the other trunk muscles was not modulated by respiration - IAP was increased during the period of limb movement - IAP increase due to rapid repetitive limb movement during breathing, this increase was maintained until the end of the task
Hodges PW. et al., 2000	4 subjects	Investigate the coordination between respiratory and postural functions of the diaphragm during repetitive upper limb movement	- - EMG recording of the costal diaphragm using intramuscular electrodes - Surface electrodes over the deltoid and erector spinae muscles	- Diaphragm activity was present throughout expiration at 78% of its peak inspiratory magnitude during repeated upper limb movement - The majority of the diaphragm EMG power was at the respiratory frequency, a peak was also present at the movement frequency - Diaphragm response was similar when movement was performed while sitting - When subjects moved with increasing frequency the peak upper limb acceleration correlated with diaphragm EMG amplitude
Hodges PW. et al., 2001	13 healthy volunteers	Investigate whether postural activity of the diaphragm changed when respiratory drive increased with hypercapnoea	- EMG of the diaphragm and other trunk muscles with intramuscular electrodes - Arm movement measured with a potentiometer - Gastric pressure recorded with a pressure transducer	- When respiratory demand is increased the postural diaphragm activity is decreased - Increased central respiratory drive may weaken the postural commands reaching motor neurons - IAP maintained elevated during arm movement and the increase during period of arm movement was reduced when ventilation increased
Hodges PW. et al., 2003	11 adolescent domestic pigs	Investigate the effect of transversus abdominis and diaphragm activity and increased IAP on intervertebral kinematics in porcine lumbar spines	- Inspiratory pressure into L3 and L4 to make movement possible, measured with motion sensors - EMG electrodes into transversus abdominis - Measurement of IAP	- Elevated intra-abdominal pressure and contraction of diaphragm and transversus abdominis provide a mechanical contribution to the control of spinal intervertebral stiffness
Hodges PW. et al., 2005	3 subjects	Determine whether spinal stiffness increased when IAP increased without concurrent activity of the abdominal and back extensor muscles	- Increase in IAP evoked by tetanic stimulation of the phrenic nerves either unilaterally or bilaterally Measurement of spinal stiffness by probe on L4 and L2, as the slope of the	- Tetanic stimulation of the diaphragm increased IAP by 27-61% and increased the stiffness of the spine by 8-31% of resting levels - Stiffness increased at L2 and L4 - When EMG activity of the erector spinae, the spinal stiffness

			- regression line fitted to the linear region of the force-displacement curve - Gastric and esophageal pressures by a thin-film strain gauge pressure transducer - Chest wall surface electrodes EMG, which don't provide selective recordings of the diaphragm, but represent evoked activity of the diaphragm in addition to any ongoing activity of the diaphragm and other muscles	increased with 16%
Jandt SR. et al., 2011	23 patients who had a clinical diagnosis of ischemic or hemorrhagic stroke	Evaluate the correlation between trunk control, respiratory muscle strength and pulmonary function in individuals who suffered stroke	- Trunk control by the trunk impairment scale - Respiratory muscle strength by manovacuometry, measuring MIP and MEP	- There is a correlation between trunk control and expiratory muscle strength
Janssens L. et al., 2010	16 people with low back pain and 12 healthy control	Determine postural stability and proprioceptive postural control strategies of healthy subjects and subjects with recurrent low back pain during acute inspiratory muscle fatigue	- Measurement of postural stability by centre of pressure displacement on a force plate - Proprioceptive postural control strategies examination by vibration of the triceps surae muscles or lumbar paraspinal muscles, while standing on a stable/unstable surface, without vision - MIP and MEP measurement by electronic pressure transducer	- Larger sway after inspiratory muscle fatigue in healthy controls - Low back pain patients already have increased sway - Inspiratory muscle increase caused an increased reliance on proprioceptive signals from the ankles, this is the same in people with LBP
Janssens L. et al., 2013	14 low back pain patients, 11 control	Whether individuals with LBP exhibit greater diaphragm fatigability compared to healthy controls	- Transdiaphragmatic twitch pressure measured before and 20 and 45 min after inspiratory muscle loading, measured by esophageal and abdominal pressure changes using balloon catheters	- Individuals with LBP showed a significantly decreased transdiaphragmatic twitch pressure - No significant decline in healthy subjects - Diaphragm fatigue was present in 80% (20 min) and 70% (45 min) after IML in LBP, only 40% and 30% in controls
Janssens L. et al., 2013	20 individuals with COPD and 20 controls	Determine the specific proprioceptive control strategy during postural balance in individuals with COPD and healthy controls, and to assess whether this was related to inspiratory muscle weakness	- Assessment of respiratory muscle strength by PImax and PEmax (measured by an electronic pressure transducer)	- COPD patients had increased ant-post body sway during upright stance + an increased post body sway during ankle muscle vibration + decreased ant body sway during back muscle vibration + increased post body sway during ankle-back vibration - The weaker the inspiratory muscles, the greater the reliance on ankle muscle input
Janssens L. et al., 2014	28 persons with low back pain (18 women and 10 men)	Investigate if inspiratory muscle training affects proprioceptive use in persons with low back pain during proprioceptive control	- Measurement of centre of pressure displacement during local muscle vibration using a six-channel force-plate - Measurement of inspiratory muscle strength by measuring maximal inspiratory pressure using an electronic pressure transducer	- PI max increased significantly by high IMT, not low IMT - A more dominant back over ankle proprioceptive use in the high IMT group - Standing on a stable support surface: the high IMT group decreased reliance on ankle proprioceptive signals + reduction of posterior body sway - Standing on an unstable support surface: in the high IMT group with vibration elicited a significantly larger anterior body sway, this is due to an increased use of back proprioceptive signals

Kawabata M. et al., 2014	11 healthy men	Measure the change in peak rate of IAP during dynamic load lifting	- Hip joint angle - Intra-abdominal pressure measured by an intra-rectal pressure transducer	- No effect of the lifting load on the time of occurrence of rate-intra-abdominal pressure - As lifting load increased, so did the time between lifting motion onset and intra-abdominal pressure onset
Kawabata, M. et al., 2010	10 highly trained judo athletes and 11 healthy men	Examine whether spontaneous breath volume and IAP altered with increased isometric lifting effort, and to compare the effect of different abdominal muscle strengths on these parameters	- Maximal intra-abdominal pressure during vasalva maneuver - Trunk muscle strength with a dynamometer	- Trained athletes had higher max%IAP during vasalva and stronger trunk flexor muscles than controls - Trained subjects had lower max%IAP during lifting task than control
Kolar P. et al., 2009	16 healthy subjects	Analyze the diaphragm movement during tidal breathing and during its activation while breath holding (subjects were instructed to firstly expand the abdominal wall, then to draw in the abdominal wall)	- Diaphragm movement by MRI (apex and dorsal costophrenic angle) - EMG	- The diaphragm is not only a breathing muscle, but activated independently of respiration - A diaphragm moves during voluntary breath-holding not only due to pressure changes but also due to active contraction
Kolar P. et al., 2010	30 healthy subjects	Describe diaphragmatic behavior during postural limb activities and examine the ventilatory and stabilizing functions of the diaphragm	- Diaphragmatic excursions measured by MRI	- Diaphragmatic excursion was greater during upper and lower body activity than during tidal breathing, with greater effect for lower limb activity - Expiratory diaphragm position was lower only for lower extremity activities - Diaphragm position was most affected at the apex of the crescent and crural portion of the diaphragm - Significant involvement of the diaphragm in the limb postural activities was found, diaphragm excursions and diaphragm positions differed from the tidal breathing conditions, especially in lower extremity activities
Kolar P. et al., 2012	18 patients with chronic low back pain and 29 healthy subjects	Examine diaphragm excursions and inspiratory and expiratory positions during normal tidal breathing and during postural tasks in patients with chronic low back pain and healthy volunteers	- Diaphragm excursion measured by dynamic MRI	- Smaller diaphragm excursions and higher diaphragm position in the patient group during upper and lower extremity tidal breathing - Maximum changes were found in costal and middle points of the diaphragm
O'Sullivan PB. et al., 2002	13 subjects with a clinical diagnosis of sacroiliac joint pain and 13 matched control subjects	Gain insight into the motor control strategies of subjects with sacroiliac joint pain and the resultant effect on breathing pattern	- Diaphragmatic excursion and pelvic floor descent were measured using US - This was measured in following condition: at rest, performing an ASLR, performing an ASLR with manual pelvic compression	- Participants with sacroiliac joint pain have decreased diaphragmatic excursion and increased pelvic floor descent
Priori R. et al., 2013	23 severe COPD patients and 12 healthy controls	Measure if varying body positions from seated to supine would influence rib cage asynchrony by changing the configuration of the respiratory muscles	- Measurement of phase shift between upper and lower rib cage and between upper rib cage and abdomen (with opto-electronic plethysmography) during quiet breathing: seated and supine position - Changes in diaphragm zone of apposition (measured by US)	- In COPD patients: - Ribcage asynchrony in seated posture but not in supine posture. - Upper ribcage and abdomen were synchronous when seated but asynchrony was found in supine - Zone of apposition of the diaphragm in healthy subjects was not significantly different in the two postures

				- Diaphragmatic displacement in COPD patients was greater seated, compared with control - Diaphragmatic displacement supine was similar in both groups
Roussel N. et al., 2009	10 healthy subjects and 10 patients with chronic low back pain	Evaluate the breathing pattern during rest (standing and supine, both while spontaneous breathing and deep breathing) and during motor control tests (bent knee fall out and ASLR)	- Monitoring of lumbopelvic movement by recording pressure changes by The pressure biofeedback unit	- In rest no significant differences between the breathing patterns of patients and healthy subjects More altered breathing patterns were observed in chronic low back pain patients during motor control tests - Changes in breathing patterns were not related to pain severity but related to motor control dysfunction
Segizbaeva MO. et al., 2013	10 healthy subjects	Evaluate MIP and EMG patterns of major respiratory and accessory muscles used in the generation of voluntary inspiratory maneuvers during different body positions	- The maximal inspiratory mouth pressure (MIP) during Müller's maneuver was measured from residual volume in standing, sitting, right-sided and left-sided lying and supine positions - EMG of the diaphragmatic, parasternal, sternocleidomastoid and the genioglossus muscles in each body position	- Parasternal EMG showed the highest level of activation in standing - Sternocleidomastoid muscle was lower in supine, RSL and LSL positions - Genioglossus EMG was greater during maximal inspiratory effort in supine, but lower in sitting, LRS and LLS positions - There were lower results of MIP as well as in men as in women, but with no significant difference
Shirley D. et al., 2003	8 subjects	Investigate whether stiffness is modulated in a cyclical manner with respiration and to investigate the relationship between stiffness and IAP or abdominal and paraspinal muscle activity	- Measurement of stiffness from force-displacement responses of a post - ant force applied over the spinous process of L2 and L4 - IAP measured by pressure transducers in the stomach - EMG activity of erector spinae L4/L2, abdominal muscles and chest wall	- Stiffness at L4 and L2 increased above base-level of functional residual capacity with both inspiratory and expiratory efforts - Changes in trunk muscle activity and IAP with respiratory efforts modulate spinal stiffness - The diaphragm may augment spinal stiffness via attachment of its crural fibers to the lumbar vertebrae
Sinderby C. et al., 1992	8 male complete cervical cord injury patients	Establish the relationship between the roles of the diaphragm during arm exercise and trunk flexion	- Esophageal and gastric pressures by a balloon catheter system - EMG activity of the diaphragm	- The diaphragm acts both as a trunk extensor muscle and a respiratory muscle - During posture imbalance, the postural needs temporarily override the respiratory needs - In trunk flexion: gastric pressure increased and esophageal pressure declined - In exercise: both gastric and esophageal pressure declined, but esophageal pressure had a larger decline in trunk flexion
Smith MD. et al., 2010	12 people with COPD and 12 healthy controls	Compare balance between people with and without COPD and determine if balance deteriorates when respiratory demand is increased by upper limb exercise	- Centre of pressure displacement by a force plate - Lumbar spine and hip motion by inclinometers	- Patients with COPD had increased mediolateral centre of pressure displacement and increased angular motion of the hip compared to healthy controls - Mediolateral centre of pressure displacement was further increased in people with COPD following exercise, but unchanged in controls
Takazakura R. et al., 2004	10 healthy men	Determine the postural difference of diaphragmatic motion between the sitting and supine positions	- MRI imaging of the diaphragm in sitting and supine position	- Diaphragmatic excursions in supine position were significantly greater than those in the sitting position
Terada, M. et al., 2016	27 patients and 28 healthy control	Examine the diaphragm contractility in individuals with chronic ankle instability and healthy controls	- Thickness of right and left hemidiaphragm at end of resting inspiration and expiration by a portable ultrasound unit - Diaphragm movement by US	- The chronic ankle instability group had a smaller degree of left hemidiaphragm contractility compared with the control group

Uchida M. et al., 2010	22 healthy males	Investigate the effects of compression on the posterior surface of the thorax caused by a pillow used for the postural changes on the respiratory function	- Subjects placed in the supine position: - Half lateral with a pillow supporting the posterior of the thorax (1) - Half lateral with pillows supporting the shoulder girdle and the pelvic band (2) Measurement: - Distance moved by the diaphragm measured by an ultrasonic imaging device	- Lower values for the distance moved by the diaphragm in (1)
Uga M. et al., 2010	2 cats	Analyze EMG of the diaphragm and trunk muscles during voluntary movements	- EMG electrodes implanted in the diaphragm costal region of both sides and trunk muscles, activity recorded during free movement in a cage - Video images	- During resting and walking alternately repeated active and inactive phases were observed in the diaphragm: respiratory activity - During stand-up the diaphragm EMG became larger and longer and irregular: non-respiratory activity
Uga M. et al., 2010	4 cats	Investigate the activity of the diaphragm and trunk muscles during voluntary movements in awake animals	- EMG recording of the diaphragm and trunk muscles - Video images	- More diaphragmatic activity after initiation of standing up movements and it occurred after the onset of trunk muscle activities - During rotation movements, left and right diaphragmatic activities showed asymmetrical discharge patterns and higher discharges than during rest - During reaching movements, diaphragmatic activity occurred prior to or with the onset of trunk muscle activities
Vostatek P. et al., 2013	17 subjects with chronic low back pain and structural spine disorders 16 controls	Present a postural analysis of diaphragm function using MRI, to identify changes in diaphragm motion and shape when postural demands on the body were increased	- MRI imaging of the diaphragm during supine lying and during supine lying with a hip flexion against load	- Faster breathing in pathological group - 3 times bigger excursions in the control group in the lying position, and 6.5 times bigger excursions in lying with load - Control group can maintain harmonicity of the diaphragm in both positions (46.7% and 46%), while a small percentage of the pathological group (29.7% and 25.5%) can maintain harmonicity of the diaphragm - Bigger postural moves in the control group
Whüthrich T. et al. 2013	11 runners and 11 cyclists	Investigate if the fatigue in leg muscles might differ between running and cycling due to inherent differences in muscle activation patterns, moreover, whether postural demand placed upon the diaphragm during running could augment the development of diaphragm fatigue	- Transdiaphragmatic twitch pressure measured with esophageal and gastric balloon catheters - Maximal inspiratory pressure measured by a handheld device - Inspiratory muscle fatigue assessed by means of phrenic nerve stimulation, measured by a differential pressure transducer	- Transdiaphragmatic twitch pressure was more reduced after 15 TT's than after 30 TT's, this is similar for runners and cyclists

Research protocol

1. Introduction

It is common knowledge that the diaphragm plays an essential role in trunk stability. Together with transversus abdominis, internal oblique, pelvic floor and multifidi it provides an increase in intra-abdominal pressure (IAP), which contributes to an increased spinal stiffness, which on turn helps to maintain trunk stability during postural tasks (Shirley et al., 2003). This knowledge could be helpful in clinical investigation or rehabilitation in certain patient populations, e.g. in low back pain patients there could be an impaired contribution of the diaphragm to trunk stability.

One manner to measure this role of the diaphragm in trunk stability is with ultrasound imaging (US), e.g. for diagnosis or feedback during rehabilitation. US can accurately measure thickening and downward displacement of the diaphragm (to be understood as activation of the diaphragm), but it is operator dependent. Advantages are that real time US of the diaphragm is a simple, inexpensive, portable imaging technique, but disadvantages are that measurements of diaphragm thickness could be highly variable depending on which intercostal space was chosen (Boon et al., 2013), and body mass index (BMI) > 30 kg/m^2 could create a risk of inability to take clear ultrasound imaging pictures (Kantarci et al., 2004).

In addition, a manner to measure diaphragm strength is through the maximal inspiratory pressure (MIP), which is an indicator for the inspiratory muscle force of the diaphragm. This measurement is also inexpensive, portable, and easy to use for diagnosis as well as in therapy (Jalan et al., 2015). A disadvantage is that MIP results give an overall interpretation of inspiratory muscle force, so it's not precisely shown which exact muscle contributes to the measured inspiratory muscle strength.

US measurements of the respiratory function of the diaphragm have been proven reliable and valid in healthy subjects (Goligher et al., 2015),(Harper et al., 2013). Though, there is little information available about US measurements of the postural function of the diaphragm. Nevertheless, US measurements during a postural task have already been studied in a couple of patient populations, but there is a lack of systematic data and evidence about reliability and validity in healthy subjects while performing a postural task like an active straight leg raise (ASLR).

During a postural task the activation of the diaphragm, in other words thickening of the diaphragm, is proven. Still, it is unclear whether this thickening is measurable and visible during a postural task when measured with US in healthy subjects. Besides, in this setting there has been little investigation on the relationship between thickening of the diaphragm measured with US and MIP.

Therefore, the aim of this study is to investigate the thickness of the diaphragm with US in supine lying and during unilateral versus bilateral ASLR. Furthermore, it is assessed if there is a correlation between the thickness of the diaphragm and the MIP.

2. Purpose research

2.1 Research question

First, is there thickening of the diaphragm and intercostal muscles during supine lying and during unilateral versus bilateral active straight leg raise (ASLR), when investigated with ultrasound imaging (US)?

Second, is this measurement with US during this task reliable?

Third, is there a correlation between thickening of the diaphragm and intercostal muscles and the maximal inspiratory pressure (MIP)?

2.2 Hypothesis

First, thickening of the diaphragm and intercostal muscles is expected during the performance of a postural task, in this case a unilateral and bilateral ASLR when compared to supine lying. Moreover, a greater increase in thickening is expected when performing a bilateral versus a unilateral ASLR.

Second, the US measurement is expected to proper interrater reliability.

Third, with greater thickness, a greater value of MIP is expected.

3. Methods

3.1 Study design

An observational, cross-sectional study design will be handled. The aim of this research is to measure diaphragm and intercostal muscle thickness at rest, during a unilateral and bilateral ASLR using US. Another aim is to observe a correlation between muscle thickness and inspiratory muscle strength and to assess the interrater reliability. This study is in collaboration with two students of Fontys University.

3.2 Participants

3.2.1 Inclusion criteria

Healthy participants in the age range of 18 - 29 years.

3.2.2 Exclusion criteria

- Pregnancy or given birth in past six months
- Musculoskeletal pain in lower back and lower extremities in past six months
- Orthopedic surgery in lumbar spine, pelvis, abdominal or thoracic area in the past year
- Neurologic disorder affecting lumbopelvic and groin regions
- Diagnosed neuromuscular diseases (e.g. weakness or paralysis of diaphragm)
- History of sensory nervous or vestibular system problems
- Lower limb injuries in the past year
- BMI > 30 kg/m^2
- Previous diagnosed lung disorders/illness (e.g. asthma)

3.2.3 Recruitment

Two students of Fontys University complete the recruitment of the participants by e-mail, flyers and oral publicity. The aim is to include at least 20 participants in the study.

3.3 Medical ethics

Before participation in this study, all participants have to sign the informed consent.

3.4 Intervention

The time span to collect the data is two weeks. The US measurements take approximately 15 minutes per examiner and the MIP measurements about 5-10 minutes. Since there are four examiners, two from Hasselt University and two from Fontys University, the participant is occupied for about an hour. Within this hour, after the US measurements, one of the two students from Hasselt University takes the MIP measurement.

US MEASUREMENT

Setting: The treatment table with adjustable height and head position will be positioned on the left side of the US machine with opaque curtains placed around the treatment table. The participant`s right side of the body will be on the side of ultrasound imaging machine. The probe of the US is placed on the anterior axillary line in the subcostal area and directed medially, cephalad, and dorsally, so that the US beam reached nearly perpendicularly the posterior part of the vault of the right diaphragm (Ayoub et al., 1997).

Execution: Prior the measurement, the participant will be provided in information as followed: “You will be asked to undress your upper body up to underwear and lay down on your back on the treatment table. After which the measurements of diaphragm and intercostal muscles on the right side of your body will be taken at rest and after a 5 second hold period during active straight leg raise test. In total you will be asked to lift your right leg three times and lifting both legs also three times given a minute of rest in between. Do you have any questions?”

The participant will be asked to undress the upper body till underwear and lay down on the table. The participant`s head will be slightly lifted with a help of a pillow and flexed to approximately 45 degrees in order to be able to see own feet, followed by instructions to keep arms rested at the sides of the body during testing and to place the heels on the sides of the white tape at the end of the table. The explanation and demonstration of ASLR test takes part. The examiner will explain that followed by certain command the participant will be asked to life right leg with knee joint kept extended 10 cm off the table - the length of the cubes on the side of the table is 10 cm, which therefore indicate the height the heels must reach. When reached, the participant will need to hold the leg there for 5 seconds after which the US picture will be taken. Followed by the command, the participant will be asked to return to the starting position and have a rest for a minute before the next measurement takes place. To ensure that the participant understood the procedure, the examiner will passively lift the leg 10 cm off the table and state “This is the position you will be asked to reach”. The explanation of breathing – the participant will be asked to breathe in and out normally with mouth opened, while breathing out the participant will be asked to stop breathing and lift the leg without an extra inhalation. To ensure the quality of the testing, the participants will be given such commands: “Open your mouth, breath in normally, breath out, stop and lift the leg”, followed by “hold”, and followed by “lower to starting position”. In total, 13 US pictures wil be taken per participant, per examiner, each before, during and between the ASLR and one at the very end. In total this provides 7 resting pictures and 6 active pictures.

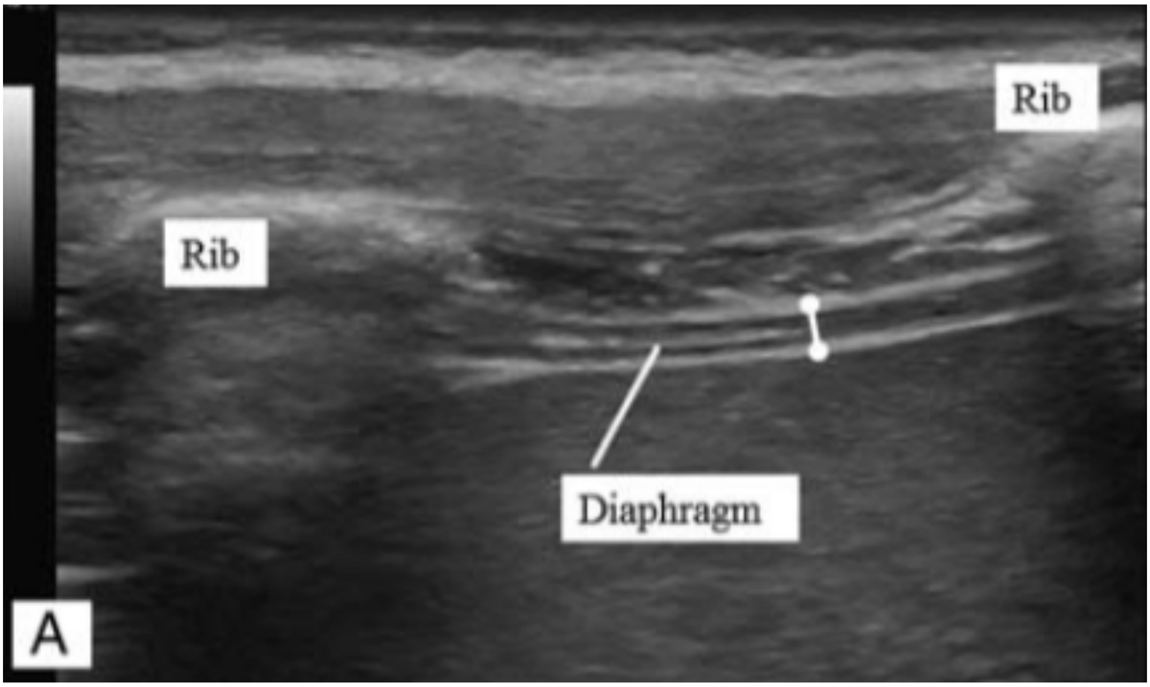

Figure 1: US image of the diaphragm and intercostal muscles (Terada et al., 2016).

MIP MEASUREMENT

Procedure: The participant will be seated on a chair with feet rested on the ground. There will be a nose clip on the nose so there would be no loss of air through the nose. Then the participant will be instructed to take the mouthpiece of the device in his mouth. The participant can hold the device himself. The researcher supports the device with one hand and with the other hand he supports the neck of the participant.

Execution: Prior to the measurement, the participant will be provided in information as followed: " First you exhale as far as possible, as long as you can, until there is no more air left in your lungs. Then, when you can't exhale any further, you will inhale in a powerful way as fast as possible." After this is done, the device will give a number, which the researcher writes down.

This procedure will be repeated as many times needed to provide at least three values that differ less than 5 cm H_2O, between each try there is a break of one minute to prevent that muscle fatigue biases the result.

3.5 Outcome measures

3.5.1 Primary outcome

- Muscle thickness of the diaphragm and intercostal muscles, measured with US.

  This is a quantitative variable and the measurement is at interval level. The thickness is eventually expressed in millimeter.

  In healthy subjects, the thickening of the diaphragm during normal breathing, measured with US, has already been proven reliable in supine. For the interrater reliability the inter-class correlation coefficient (ICC) was 0.97 (95% CI: 0,91-0,99) for inspiratory thickening and 0.98 (95% CI: 0.94-0.99) for expiratory thickening of the diaphragm (Harper et al., 2013). For the intrarater reliability the ICC was 0.94 (95% CI: 0.79-0.98) for inspiratory thickening and 0.98 (95% CI: 0.94-0.99) for expiratory thickening of the diaphragm (Harper et al., 2013). US measurements are therapist dependent, but with practice and adherence to the criteria to make a proper image, this measurement of diaphragm thickening should be reproducible (Cohn et al., 1997).

  In healthy subjects, the validity of diaphragm thickening measurements with US has also already been proven. Diaphragm thickening was correlated to inspiratory volume (r^2= 0.32; p= 0.0001), to diaphragm EMG (r^2= 0.32; p= 0.01) and IAP (r^2= 0.28; p= 0.01) (Goligher et al., 2015).

3.5.2 Secondary outcome

- Inspiratory muscle strength, presented as the MIP, measured with the kinetic power breath.

  In healthy subjects, there is need of one practice session to become a reliable measurement and five measurements are needed to become 3 reproducible values (Smeltzer & Lavietes, 1999). There could be day to day fluctuations of 10% (Volianitis, McConnell, & Jones, 2001). However, it is a reliable measurement tool for most of the parameters (Romer & McConnell, 2004). In addition, the between-day reliability improves when the measurements are preceded by an inspiratory muscle warm-up. This could provide a MIP improvement up to 21%. Also, five to six attempts are needed to reach the maximal MIP (Lomax & McConnell, 2009). Furthermore, the intra-class correlation coefficient for intra-rater and inter-rater reliability was respectively 0.962 and 0.922. This is highly reliable, because values above 0.8 are considered highly reliable (Jalan et al., 2015).

- Test retest reliability of US measurements

3.6 Data analysis

The analysis of the data will be performed in JMP. The results of this study wil be dependent, because there will be repeated measures on the same participant. That’s why a linear mixed model analysis will be used.

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5. Attachments

INFORMATION LETTER

Dear participant,

Thank you for consideration to participate in our research. With this letter, we would like to provide you with information about the aim of the research, criteria for participation, the testing procedure, expectations and other important information for you as a potential participant. We would kindly ask you to carefully read through the information below. In a case of uncertainty during or after reading this information letter please do not hesitate to contact the researcher via email or phone number provided in the email you received.

What is the aim of the research?

Abdominal wall muscles, such as Transversus Abdominis, Internal and External Oblique muscles, diaphragm and intercostal muscles play a major role in spinal stability during functional activities. For this reason, the aim of this research is to measure above-mentioned muscle thickness at rest, during an active straight leg raise test and bilateral straight leg raise using musculoskeletal ultrasound imaging. Another aim is to observe a correlation between muscle thickness and a performance of a dynamic balance task and inspiratory muscle strength.

Who can participate?

We are looking for healthy participants in the age range of 18-29 years. Other requirements to participate are:

1. No pregnancy or delivered baby in past 6 months
2. No musculoskeletal pain in lower back and lower extremities in past 6 months
3. No orthopedic surgery in lumbar spine, pelvis, abdominal or thoracic area in the past year
4. No neurologic disorder affecting lumbopelvic and groin regions
5. No diagnosed neuromuscular diseases (e.g. weakness or paralysis of diaphragm)
6. No history of sensory nervous or vestibular system problems
7. No lower limb injuries in past year
8. BMI between 18.5 - 29 kg/m^2
9. No previous diagnosed lung disorders/ illness (e. g. asthma)

What is the procedure of the testing?

If you match the participation criteria and decide to participate in the study, at the time of meeting you will be asked to sign consent form, which serves as a proof of your agreement to participate in the research. The data collection will begin with measuring your weight and height in order to calculate your body mass index. After which the measurements with ultrasound imaging, performance of a dynamic balance task and measurement of inspiratory muscle force will take place.

Your abdominal muscles (Transversus abdominis, internal and external oblique, intercostal muscles and diaphragm) will be measured at rest, during active straight leg raise and bilateral leg raise in laying position. For ultrasound imaging picture collection, a linear transducer with gel will be used and applied on your skin on both sides of your body. You will also be asked to perform a postural balance task called Dynamic One-leg Stance Test (DOLS). The test consists of 5 consecutive levels with three trials on each level. After which the measurement of inspiratory muscle strength will take place.

Figure 1: Information letter first page

What is expected from you?

We expect you to independently come to the explore lab at D. Th. Fliednerstraat 2, 5631 BN Eindhoven.

We expect you to wear comfortable clothes and agree on undressing your upper body until underwear.

What happens to data collected during testing procedure?

All the recorded data will be kept confidential and anonymous and will be accessible only to researchers, research supervisor who is a representative of Fontys University of Applied Sciences and the clients of the research. The collected data of ultrasound imaging will be stored for 15 years at Fontys University of Applied Sciences and deleted from researchers` personal computers once the research is over.

What happens if you decide to withdraw from testing procedure?

The participation in this research is voluntary; therefore you are allowed to withdraw your participation at any time without providing an explanation.

What happens after testing procedure?

The entire testing procedure is expected to last about 1 hour, after which you will be offered tea and snacks as an appreciation for participating in our research.

Are there extra costs/compensations for the participation?

There are no extra costs or monetary compensations for the participation in this research.

Are there any questions left after reading the information above?

If you have decided to participate or have any questions, please do not hesitate and contact one of the researchers, who will send you the schedule of available testing dates and times:

LAURA JANITE **l.jante@student.fontys.nl** **+31648054664**

Thank you for your time and interest,

Sincerely,

Laura Janite, Marija Gusiatina, Niki Budai, Eva Shalley and Josefine Smeets

Figure 2: Information letter second page

Informed Consent form

Participant no: _______

I volunteer to participate in a research project "Ultrasound measurement of changes in thickness of internal and external oblique muscles during active straight leg raise" conducted by Laura Janite, 4th year student of Fontys University of Applied Sciences, Eindhoven, The Netherlnads.

1. I have read and understood the information provided in information letter.

2. I was given enough time to decide whether to participate in the research or not.

3. I understand that I can withdraw and discontinue participation in the project at any time without explanation and penalty.

4. I understand that all of the information collected will be kept confidential and that the results will only be used for scientific objectives.

5. I have been given the opportunity to ask questions and have had them all answered to my satisfaction.

6. My signature on this form signifies that I freely give my consent to participate in this study.

My name: ______________ ________ Signature: ___________________ Date: ___/___/_______

I hereby declare that I have provided the participant with all the necessary information about the research. The participant was provided an opportunity to ask questions, and I answered them with my best ability. I declare that the all the gathered information about the participant will be kept confidential as stated in information letter.

Signature of the researcher: __________________

Figure 3: Informed concent

Form of Personal Data Collection

Participant no:______________

Age:______________________

Gender: Female/ Male

Height: ____________________

Weight:____________________

BMI: ______________________

Figure 4: Personal data collection

VOORTGANGSFORMULIER WETENSCHAPPELIJKE STAGE DEEL 1

DATUM	INHOUD OVERLEG	HANDTEKENINGEN
24-10-2016	Bespreking en invullen contract. Concretiseren van aanpak (eerste researsch in het studiedomein): opstellen onderzoeksvraag (keywords / MeSH termen afbakenen), in-/exclusiecreteria bepalen.	Promotor: Dr. Janssens Lotte Student(e): Schalley Eva Student(e): Smeets Josefine
16-01-2017	Eerste selectie artikels bespreken, eventuele verdere selectie, kwalitietsbeoordeling full-teksten, data-extractie (welke variabelen).	Promotor: Dr. Janssens Lotte Student(e): Schalley Eva Student(e): Smeets Josefine
22-03-2017	Aanleren ultrasoud metingen voor data verzameling MP2 door professional in Fontys, Nederland. Bespreken protocol voor MP2.	Promotor: Dr. Janssens Lotte Student(e): Schalley Eva Student(e): Smeets Josefine
05-04-2017	Oefenen ultrasound metingen in gebouw A, Diepenbeek. Verder bespreken aanpak voor het uitvoren van de data verzameling.	Promotor: Dr. Janssens Lotte Student(e): Schalley Eva Student(e): Smeets Josefine
12-05-2017	Het verder uitwerken / suggesties ter verbetering van de resultatensectie en discussie bespreken. Tips voor het maken van de presentatie. Terugblik op data verzameling van MP2 (deze is reeds gebeurd in Fontys), bespreken hoe we deze data reeds kunnen anlyseren in de zomervakantie en gedeeltelijk bespreken hoe MP2 thesis er zal moeten uitzien (grote lijnen)	Promotor: Dr. Janssens Lotte Student(e): Schalley Eva Student(e): Smeets Josefine
24-10-2016 tot 18-05-2017	Promotor en studenten zijn via E-mail in contact gebleven voor feedback op het schrijf proces en regelingen omtrent de data verzameling van MP2	Promotor: Dr. Janssens Lotte Student(e): Schalley Eva Student(e): Smeets Josefine

Auteursrechtelijke overeenkomst

Ik/wij verlenen het wereldwijde auteursrecht voor de ingediende eindverhandeling:
The role of the diaphragm in trunk stability: a systematich overview of the measurement tools

Richting: **master in de revalidatiewetenschappen en de kinesitherapie-revalidatiewetenschappen en kinesitherapie bij inwendige aandoeningen**
Jaar: **2017**

in alle mogelijke mediaformaten, - bestaande en in de toekomst te ontwikkelen - , aan de Universiteit Hasselt.

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Voor akkoord,

Smeets, Josefine **Schalley, Eva**