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Phrenic nerve and cervical functional interdependence and its sensorimotor anomalies: A musculoskeletal pain consideration review

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ABSTRACT

Background: Optimal breathing occurs when using the diaphragm muscle, which is known as diaphragmatic breathing. Any disruption or faulty habit of this breathing pattern would result in breathing pattern disorders (BPDs).

Objectives: The aim of this review is to shed light on the importance of detecting the presence and extent of asymptomatic functional anomalies of cervical segments among individuals with breathing pattern disorders.

Materials and methods: This narrative review was performed by searching in MEDLINE using terms related to phrenic nerve and cervical functional, interdependence, and sensorimotor anomalies. Additionally, articles regarding this topic were extracted in full for a comprehensive and critical analysis. Any study design, such as observational studies, systematic reviews, or narrative reviews, was included. The results were narratively synthesized and described.

Results: Breathing is a physiological process that occurs without any conscious effort. Optimal breathing utilizes the deep diaphragmatic muscles, which lead to filling the lungs with air more efficiently. However, breathing pattern disorders may result from inadequate diaphragm use. BPDs can lead to structural musculoskeletal pathologies, including neck, low back, temporomandibular joint pain, and/or scapular dyskinesis. BPDs cause motor reflexive changes in the cervical spine, which may contribute to pain, restriction, and functional impairments.

Conclusion: Early identification of this faulty habitual suboptimal breathing is required to minimize its adverse effect, which can be disruptive to the motor control mechanism.

Introduction

Breathing is an essential and constant series of oxygen and carbon dioxide gas exchanging cyclic activity humans do, yet most individuals are unaware of how breathing persistently happens, and little attention is often paid to it throughout the day. Optimal breathing is referred to diaphragmatic breathing, which is three-dimensional in nature, and it utilizes the diaphragm muscle to perform adequate functionality[1] (Figure 1). Also, it involves synchronous movement of the abdomen and lower rib cage.[2] Normal eupneic breathing can be affected by multiple factors, including biomechanical, biochemical, and psychological, etc..[3-6]

However, faulty/suboptimal breathing patterns occur when the diaphragm is not adequately used for

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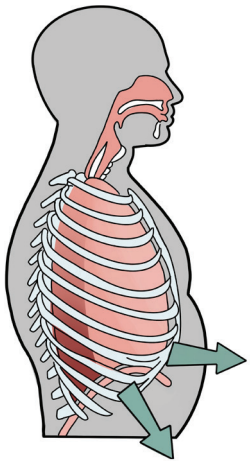

Figure 1. *Diaphragmatic Breathing/Belly Breathing.*

breathing, and it results in breathing pattern disorders (BPDs) or hyperventilation syndrome (HVS). BPD is defined as inappropriate breathing that is persistent enough to cause symptoms with no apparent organic cause.[7] However, a paradoxical breathing pattern, which is considered the most extreme form of BPDs, is often accompanied with muscle imbalance and/or dysfunction and cervical spine pain.[8,9] It is postulated that BPDs have a detrimental effect on functional movements by affecting the motor control of cervical, scapular, and lumbar segments.[10] As like poor posture, a poor breathing pattern is not a disease but a disorder. BPDs, which are habitual, can lead to various faulty functional adaptations, which in turn may cause structural musculoskeletal pathologies, such as neck,[11] low back,[12] temporomandibular joint pain,[13] and scapular dyskinesis.[3] BPDs functional anomalies cause reflexive changes in cervical structure, which are insidious and without pain. Moreover, these faulty habitual patterns act physically and physiologically against biologically sustained patterns and, in a vicious cycle, promote abnormal function and alter structure, which then prevents the return to normal function.

The adaptation reflex continues to progress up to a point where the adaptive capacity is exhausted and symptoms inevitably emerge involving pain, restriction, impairments, and structural breakdown.[14] Early identification of these reflexive motor control changes in the cervical region due to BPD is imperative to preclude the incidence of further debilitating cervical structural anomalies. Up to our knowledge, no studies have been conducted to find out the presence and extent of asymptomatic functional anomalies of cervical segments among individuals with BPDs. Also, its extended adverse effects have not been further studied in this population.

Diaphragm and breathing pattern disorder

Literature explained breathing as a constant, fundamental, and automatic act of supplying oxygen through physiological respiration and mechanical ventilation. Respiration is the exchange of gas between lungs-alveoli and capillaries, whereas ventilation is the process of inhalation and exhalation, i.e., air goes in and out of the pulmonary system. On the contrary, breathing is not a mere oxygen supply process only, but it is also associated with the well-being of the entire body system, maintaining allostasis[8] along with providing biomechanical stability and mobility of the trunk and spine.[2] The diaphragm, which is the primary respiratory muscle, contributes to 70-80% of respiratory force, and it has also been evaluated for its role as postural, sphincteric, visceral, and metabolic functions.[8,14] This horizontal dome-shaped muscle is a repertoire having a primary role in respiration,[8] and a secondary role in the trunk and postural stability,[10] spinal decompression,[15] emotional regulation,[16] visceral mobility,[17] and fluid dynamics.[18]

Among the general population, BPDs are more common than reported.[8] It is estimated that 10% of the population is affected by BPD, which escalates to 30% with asthma sufferers and 83% in individuals with anxiety.[14] An average of 10% of patients in a population are diagnosed with HVS.[19] However, suboptimal breathing is more prevalent in women (14%) than in men (2%).[20] Many individuals breathe inefficiently by having shallow breathing or using upper chest muscles instead of utilizing diaphragm muscles, which do not meet the physiological needs of humans (Figure 2). These breathing pattern changes are unnoticed as it is subtle, yet clinically significant.[20] BPDs may range from simple upper chest breathing to hyperventilation to the most extreme form of paradoxical breathing (Figures 3 & 4).[21] In paradoxical breathing, the chest and abdominal muscle functions are in an opposite pattern, i.e., the patient inhales using the chest muscles.[22] When breathing becomes dysfunctional, a general sequence of progressive, adaptive changes results from BPDs.[14] The sensory-motor system often utilizes the secondary respiratory muscles, which are over-activated. These accessory and superficial muscles (Sternocleidomastoid, Scalenus, Upper

trapezius, Pectoralis Minor and Major, and Levator scapulae) become hypertonic,[13] which can lead to the development of trigger points[24] that become fibrotic, and will also be palpable and observable. As a result, the head is protruded forward, and the shoulders are hunched anteriorly and pulled forward.[24,25] Progressively, the lower cervical spine becomes rigid with fixed lordosis and decreased mobility of the second cervical segments and second rib.[26] Figure 5 shows the etiopathogenesis of PBDs affecting the cervical motor control mechanism.[25]

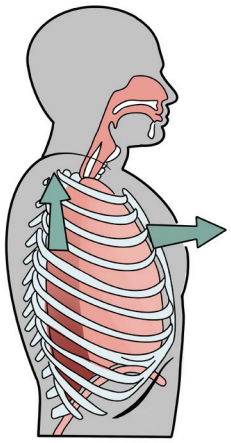

Figure 2. *Chest breathing.*

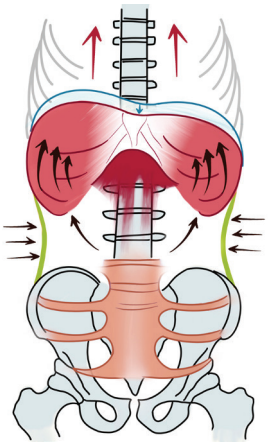

Figure 3. *Paradoxical inspiration.*

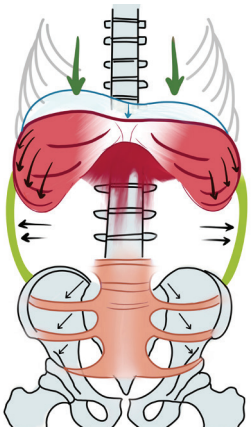

Figure 4. *Paradoxical expiration.*

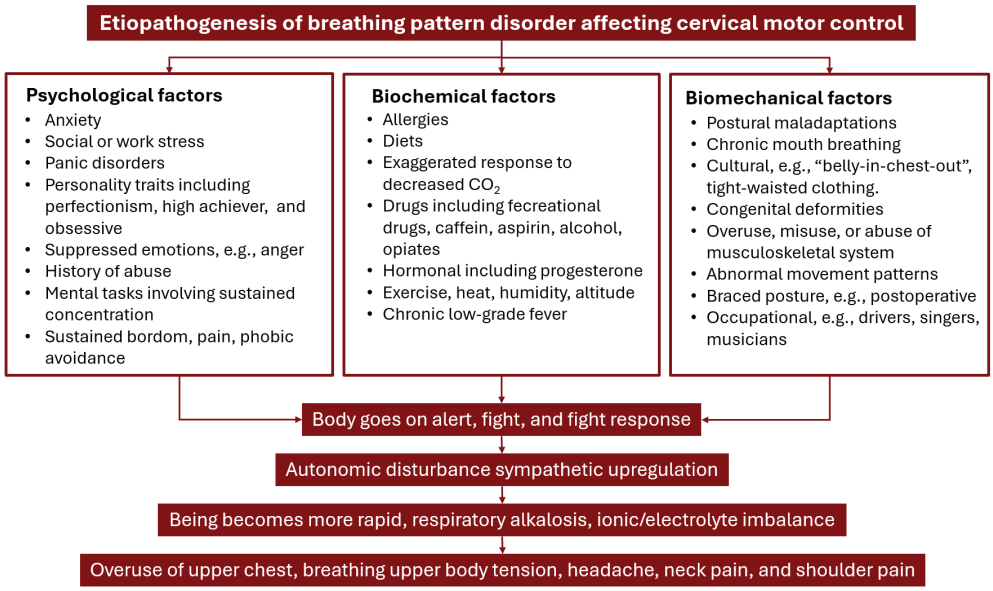

Figure 5. *Flow chart showing the etiopathogenesis of breathing pattern disorders affecting cervical motor control.*

Cervical disorders

The cervical spine is a mobile segment providing a wide range of movement. Usually, activities of daily living (ADL) utilize 30% to 50% of cervical ROM.[27] In regard to neck stability, muscle strength is critical to maintain proper alignment, smooth movement, and stabilization. Nevertheless, cervical structural and functional pathologies exhibit an increasing prevalence in the present-day population, and it is associated with a significant morbidity rate. As a great number of individuals are becoming accustomed to electronic gadgets and indulging in tabletop jobs, neck pain and related symptoms are reported to be the most common disorders which affect approximately 66% of the population at some stage of their lives.[28,29] Even though a large population suffers from neck pain, people may not experience a complete recovery of symptoms as it is difficult to be diagnosed and managed.[30] Secondary muscle activation in BPD is linked to neck pain,[11] trigger point formation,[31] and scapular dyskinesis.[32] Chronic neck pain is usually diagnosed without a history of trauma, structural involvement, and poor posture, which is referred as mechanical neck pain.

Functional neurology delineates the phrenic nerve and cervical neural interconnectivity through the cervical from C_1 to C_4 and brachial from C_5 to T_1 plexus, sharing its roots for the phrenic nerve from C_3 to C_6, which supplies the diaphragm. BPDs induce aberrant neural drive that can cause symptoms like motor control dysfunction in the neck, shoulder, and arm, along with brachialgia and thoracic outlet syndrome (TOS), etc. (Figures 6 and Figure 7).[33,34] Furthermore, the central or rural portion of the diaphragm is innervated by vagus nerve, thus diaphragm dysfunction will affect the cervical base, floor of the mouth, eyes, and the dura matter via vagal connection to the trigeminal nucleus through the medial longitudinal fasciculus.[35,36] The trigeminal nucleus is connected to C_2-C_4 nerve roots,[35,37,38] rectus capitis posterior minor,[39] and nuchal ligament, which is directly connected to dura.[40]

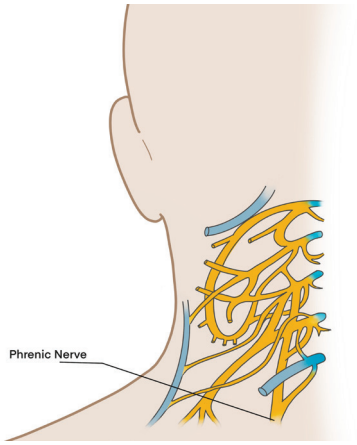

Figure 6. Phrenic nerve and its relation to the brachial plexus.

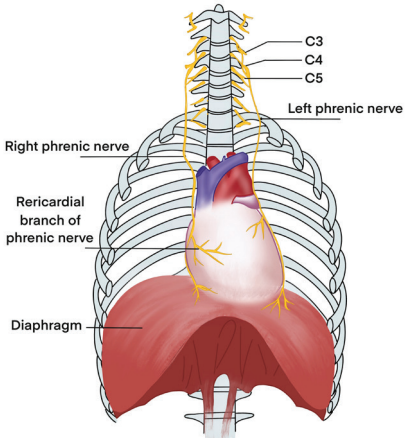

Figure 7. Phrenic Nerve and its branches.

Somatosensory alteration

Humans are born with a basic movement control system called primitive reflexes, balance, and righting reactions. Through both asymmetric tonic neck reflex (ATNR) and symmetric tonic neck reflex (STNR), the cervical spine facet proprioceptors/mechanoreceptors contribute to the function and protection of the cervical spine,[41] postural stability,[42] and they play a significant role in cervical pain.[43] Small and slender suboccipital muscles have more proprioceptive receptors than those of lower extremity large muscles, such as the gluteus maximus.[44,45] Excessive neural drive due to BPD primarily affects the lower threshold tonic motor neurons supplying deep cervical muscles, which are crucial in maintaining stability, motor control, and the optimal instantaneous axis of rotation (OIAR). BPD induces neural dysfunction, which causes anomalies in suboccipital muscles, triggers neck pain, and radiates pain in the relevant dermatome or myotome distribution pattern.[46]

These breathing disruptions induce cervical, neural, and muscular mechanisms that remain sub-clinical as functional instability for months and years until symptoms eventually emerge. Functional instability is defined as the sensation of instability or recurrent sprain (or both) due to proprioceptive neuromuscular deficit,[47] which is clinically exhibited as recurrent neck knots (wry neck), neck sprain, chronic neck pain, cervicogenic headaches, suboccipital muscular atrophy,[48] and standing balance deterioration.[49] The movement control system is functioning by controlled and coordinated activity of three subsystems, i.e., the motor control system (CNS), the passive support system (Skeletal System), and the active movement system (Muscular System). Dysfunction of any of these subsystems debilitates stability and causes pain.[50] This functional instability of any of the subsystems is compensated by the higher motor system using one or more subsystems, which is achieved by altering muscle activation and movement patterns. Eventually, it becomes ingrained in the motor cortex, and later individuals may find it difficult to retrain to normal, even with conventional rehabilitation approaches. The long-term utilization of these adaptive mechanisms leads to the inception of irreversible structural pathologies. Thus, BPDs can be disruptive to the motor control mechanism.

Anomalies of the autonomic nervous system

Human body allostasis is effectively regulated by the autonomic nervous system (ANS) through various involuntary systems in the body, like the respiratory, muscular, circulatory, lymphatic, and endocrine systems.[51,52] ANS with its branches, sympathetic nervous system (SNS) and parasympathetic nervous system (PNS), responds to different perceptions such as pain, fear, anxiety, and other emotional stressors by adjusting breathing, muscle tone, heart rate, blood pressure, and hormones.[53,54] Generally, the ANS passes the diaphragm through the central crural region.[55,56] This suggests that any anomalies in the diaphragm, such as spasm or atrophy, will have deleterious effects on ANS in both up and downward directions, affecting the visceral organs as well as the metamers innervated by the ANS plexus such as muscles and vertebral facets leading to chronic pain.[57-59] "Up-regulation" is referred to as the heightened and aroused response of the sympathetic nervous system.[60] Continuous "Up-regulation" of SNS predisposes to alteration in breathing pattern by changing the motor control pattern and also the respiratory muscle recruitment pattern[61] leading to BPD, acute or chronic musculoskeletal pain.

Persistent body function with an "up regulated" ANS leads to hypersensitivity to touch, hyper-reflexia, and exaggerated pain perception. Normal palpation or stimulus causes increased pain perception and withdrawal or removal of the body part in a pattern for protection.[60] These hyperactive startle responses theoretically delineate the cause and perpetuation of musculoskeletal pain without an organic cause in patients with BPDs.[62] This stage is very challenging for the therapist to approach patients, as any attempt will be excruciating for the subject.[63]

Regional interdependence

There is a growing awareness about the concept of regional interdependency. Human body systems are integrated and interconnected as fascio-neuro-skeletally to depend upon each other locally, regionally as well as globally. The concept of regional interdependence began with the underlying thought process, which describes the human body as a kinetic chain.[64] This theory suggests that if one part of the kinetic chain is unable to perform any motor pattern sufficiently, another part of the body will compensate for the deficiency.[64]

Though muscles function individually, they are functionally interconnected across the body with fascial webbing traced as "myofascial meridians". These fascial meridians distribute and transmit tension, strain, fixation, stability, resilience, and postural compensation to other remote portions of the body. The deep front line (DFL) myofascial meridian better explains the relationship between the diaphragm and cranio-cervical region. DFL through its upper posterior line, upper middle line, and upper anterior line connects the diaphragm to the cranio-cervical region.[65] The upper posterior line connects the posterior diaphragm, anterior longitudinal ligament, and longus coli to longus capitis while the upper middle line connects the central tendon of the diaphragm, pericardium, mediastinum, parietal pleura, fascia prevertebralis to scalenes. However, the upper anterior line connects the anterior diaphragm, transversus thoracis, infrahyoid, and suprahyoid to the jaw muscles.

The dysfunctional breathing patterns might create a variety of negative physiological and biomechanical adverse effects on the entire myofascial line. Decreased diaphragm mobility causes cervical erector spinae hypertonicity, ribcage hypomobility, and thoracic prevertebral muscle tightness, which may lead to exaggerated thoracic kyphosis, cervical hyperlordosis, and capital extension.

Conclusion

It is axiomatic that in chronic neck conditions, pain and movement dysfunctions are not always due to the structural theory of pain-spasm-pain; on the contrary, pain results from muscular adaptation due to breathing pattern disorder mediated by the CNS. Hypertonicity of accessory muscles of respiration due to constant activation, eliciting a muscle imbalance syndrome (not a symptom) because of functional pathology leading to cervical motor control disorder. A breathing pattern assessment in patients with neck pain can attribute to a differential diagnosis between structural and functional cervical disorders. Pain is a protective response to muscle overuse or trauma, which has to be addressed and corrected promptly. Future research should investigate the effect of breathing pattern retraining on musculoskeletal pain syndrome to provide clinicians with evidence for integrating breathing retraining into their clinical practices.

Ethical approval

This is a review study for already existing data, and it did not directly involve human subjects. Therefore, ethical approval was not required for this paper.

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Conflict of interest

The authors declare no conflict of interest.

CRediT authorship contribution statement

Shaheem Rasheed: conceptualization, investigation, methodology, writing original draft; **Mashael Alsobhi**: conceptualization, investigation, resources, writing, review and editing; **Mohamed Faisal Chevidikunnan**: investigation, conceptualization, methodology, visualization, validation, reviewing and editing; **Fayaz Khan**: conceptualization, visualization, validation, project administration, reviewing and editing.

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