Medical Research Archives

European Society of Medicine

OPEN ACCESS

Published: January 31, 2024

Citation: Ong KC, 2024. Clinical Evaluation of Dyspnoea in Obstructive Lung Disease – Progressing from Psychometrics to Physiology, Medical Research Archives, [online] 12(1). https://doi.org/10.18103/mra.v12i2.5019

DOI
https://doi.org/10.18103/mra.v12i2.5019

ISSN: 2375-1924

RESEARCH ARTICLE

Clinical Evaluation of Dyspnoea in Obstructive Lung Disease – Progressing from Psychometrics to Physiology

Kian Chung Ong

Chestmed Private Limited, Mount Elizabeth Medical Centre, 3 Mount Elizabeth #12-03 Singapore 228510

***Correspondence:** ongkc@chestmed.com.sg

ABSTRACT

Dyspnoea is a common symptom that afflicts persons with myriad medical conditions. Among sufferers of lung disorders such as chronic obstructive pulmonary disease, dyspnoea, together with effort intolerance, are the major complaints. Dyspnoea is a marker of disease severity and adverse prognosis of chronic obstructive pulmonary disease, and the need for symptom alleviation in improving health status is ever-present, but the quantification of this symptom is challenging in clinical practice, and is mostly limited to the use of questionnaires and self-reports currently. Numerous psychometric tools have been developed to measure the severity of dyspnoea clinically, but their utility is vitiated by the complexity and multidimensional nature of the symptom. The lack of a universally accepted and accurate measurement tool is likely to hinder future progress in developing novel treatments for relieving dyspnoea.

Physiological measurements have been used to complement or supplant psychometric evaluation of dyspnoea but simple stationary lung function tests do not correlate sufficiently well with dyspnoea severity in patients with chronic obstructive pulmonary disease, while complex exercise testing is impractical or limited to specialized research labs. In recent years, the use of non-invasive surface electromyography of the diaphragm and/or accessory muscles of respiration is gaining attention as a promising physiological assessment of dyspnoea with potential for widespread clinical applications. Although substantial technological gaps still exist between bench and bedside, the current interest, as evidenced by the number of med-tech collaborations in surface respiratory electromyography, appears to be well justified. This review aims to summarize the past and present methodologies as well as future developments in evaluating and quantifying dyspnoea, especially in patients with chronic obstructive pulmonary disease.

Introduction

In a seminal paper on clinical methods of evaluating dyspnoea,[1] Mahler and Wells assessed the utility of extant self-ratings and questionnaires, viz., the baseline dyspnoea index (BDI) and the Medical Research Council (MRC) scale. The authors opined that the clinical measurement of dyspnoea is important for 3 reasons – dyspnoea is a frequent symptom in patients with medical and respiratory conditions, it impacts negatively on health status and rating dyspnoea is essential for establishing the efficacy of therapy. Despite advancement in the understanding of dyspnoea in health and diseased states through the years, and the interim publication of 2 official American[2,3] and a European[4] statements on dyspnoea, current consensus maintains that there are "far more instruments for measuring dyspnea than there are treatments. This profusion of measures makes it very difficult to compare results across studies and draw evidence-based conclusions."[3] Three and a half decades after Mahler and Wells, the same requirements for clinical measurement of dyspnoea are partially met, numerous grading instruments have surfaced but the MRC scale and BDI remain the most utilized situational measurement tools in clinical practice and research. The present review aims to explore the challenges, progress (or the lack of it), and possible new directions in the clinical evaluation of dyspnoea, especially in patients with chronic obstructive pulmonary disease (COPD).

Current concepts in understanding dyspnoea in chronic obstructive pulmonary disease

Recent developments have led to a better comprehension of the dyspnoeic sensation in healthy individuals and in patients with COPD. The pathophysiological basis leading to the increased awareness of dyspnoea in patients with COPD have been well described elsewhere.[5,6,7] Increased perceived breathing effort is believed to reflect the awareness of increased motor command output to the respiratory muscles (respiratory neural drive) via the augmented central corollary discharge from the respiratory motor centres to the somatosensory cortex.[4] In other words, respiratory motor areas of the brain, can send an ascending copy of their descending motor activity to perceptual areas (corollary discharge), and the overall sensation of dyspnoea is processed in the higher somatosensory cortex.[3] In COPD patients, there is a mismatch between increased neural drive and altered peripheral mechanoreceptor afferent feedback that gives rise to neuroventilatory dissociation and the associated perception of unsatisfied inspiration.[6,8]

Fundamentally, dyspnoea is a complex sensation that may be defined as breathing discomfort that consists of qualitatively distinct sensations that vary in intensity.[2] The term breathing discomfort is vague and may convey different meaning for different individuals. Indeed, the qualities of dyspnoea are known to differ and there are at least four different somatic descriptors of breathlessness among COPD patients: (1) perceived sense of increased work or effort; (2) sense of chest tightness; (3) air hunger or an uncomfortable urge to breathe; and (4) unsatisfied inspiration.[8] These separate qualities of dyspnoea are likely to exist in combination within the same patient and vary in composition and intensity according to the current physical activity level, affective states, and the surrounding environment. While dyspnoea may generally be attributed to neuroventilatory uncoupling as described above, with so many possible afferent sources affecting dyspnoeic sensation, the COPD patient cannot be expected to distinguish the qualities of dyspnoea or to quantify each type and average them out throughout the day, which is what one would expect from a subjective measure of a patient reported outcome.[3] In the next section, the nuances of clinical measurement of dyspnoea intensity will be discussed.

Measurement of Dyspnoea

Since dyspnoea is a complex and multidimensional symptom that can be perceived only by the person experiencing it,[3] clinicians have long relied upon patients' self-reports to assess and quantify dyspnoea. However, knowing that different qualities of dyspnoea that may be perceived by a patient with COPD singly or in combination, depending on activity level, psychological and environmental factors as described above, it is little wonder that there is currently no universally accepted self-rating tool for dyspnoea measurement. The American Thoracic Society statement[3] that highlighted a "profusion of measures" enumerated at least 54 such measures in 2012, and newer ones have since been added, either disease-specific[9] or site-specific.[10] As affective distress garner increasing attention, 'multidimensional' diagnostic approaches that incorporate the affective dimension and negative sensor descriptors in quantifying dyspnoea have also gained awareness.[11]

In general, measurement tools for dyspnoea may be classified into three distinct sets: (1) short-term measures of intensity of dyspnoea, e.g., Borg scale and visual analog scale (VAS); (2) situational measures, e.g., the baseline dyspnoea index, the transition dyspnoea index (BDI-TDI) and the mMRC dyspnoea scale; (3) impact measures of dyspnoea

on functional status or health status, e.g., the Chronic Respiratory Questionnaire.[7] Another way to "classify" measurement tools is by the domains of dyspnoea that they measure: sensory-perceptual experience (e.g., Borg and VAS scales), affective distress, symptom impact or burden (e.g., MRC and scales of health status).[3]

Pros and cons of each class of dyspnoea measurement tool exist. Situational measurement tools are not able to separate activity level from dyspnoea intensity since the listed activities are standardized for comparison purposes. Situational questionnaires are subject to recall biases, causing the rates of dyspnoea to differ from experienced (momentary symptoms). Sandberg et al recently demonstrated that subjects more likely to recall the peak breathlessness they experienced throughout the week when asked at the end of the week but tended to record the mean breathlessness level when asked to score at the end of each day.[12] Short-term dyspnoea scores are easy to use and widely available but requires the activity level to be standardized to be clinically useful for comparison and this is no mean feat (to be discussed later). Mahler asserts that patient-reported dyspnoea based on activities of daily living and exercise testing provides distinct but complimentary information in COPD patients.[13] Furthermore, the BDI score was strongly significantly correlated with mortality, whereas the Borg score at peak exercise testing was not, indicating that dyspnoea with activities of daily living is a better measurement for evaluating the disease severity of COPD than peak dyspnoea during exercise.[14] There is no measurement tool currently used in clinical practice that are capable of simultaneously grading both immediate and longer-term changes in dyspnoea. The third set of measures that quantifies the impact of dyspnoea on health status and functional status do not quantify dyspnoea *per se* and are thus less precise in rating dyspnoea.

The measurement of dyspnoea discussed thus far belongs to the realm of psychometrics, the process of measuring subjective outcomes, though psychometrics has classically been associated with psychological tests of intelligence and personality. Nonetheless, the current practise of using questionnaires and self-reports to measure dyspnoea are subject to the principles of psychometrics, i.e., the reliability and validity of symptom-based instruments for measuring subjective outcomes should be considered. In psychometrics, the validity of an instrument like a questionnaire for rating dyspnoea is typically predicated on the hypothetical inference that dyspnoea correlates well with attributes of the population, e.g., health status or functional status.[15] Thus, by establishing that the dyspnoea instrument correlates well to another instrument that measures health status or functional status, the validity of the dyspnoea instrument is strengthened indirectly. This is usually the way to establish the validity of the original dyspnoea questionnaire because there is no objective gold standard by way of comparison. In fact, the more such hypothesized associations between different types of attributes with dyspnoea can be proven, the greater is the confidence in the instrument's validity. Although an instrument like the MRC is well correlated with a health status instrument like the St George's Respiratory Questionnaire in COPD patients, as well as instruments for functional capacity e.g., the Functional Assessment of Chronic Illness Therapy Fatigue score, and the Short-form Health Survey physical component score (SF-12 PCS), it remains hypothetical that MRC measures dyspnoea directly, and the possibility that it measures another attribute that correlates well with health and functional status cannot be ruled out.

Another major consideration in psychometrics is regarding the optimization of the reliability coefficient of an instrument. The development of a measure that yields an acceptable reliability coefficient requires its development in a heterogenous population. Even if this is done, the same instrument of measure is likely to yield a lower reliability coefficient when used in a significantly different population from the one in which it was developed.[15] Greater heterogeneity of a characteristic increases true variance. This mandates that testing and use of instruments be on similar populations. Given that the qualities of a complex symptom like dyspnoea is known to vary even in a specific population like patients with COPD, one wonders if the essentials for reliability value of a psychometric instrument for quantifying dyspnoea are being met at present. In addition, the potential reliability coefficient of an instrument can be improved by raising the number of questions and the number of response options for each question. However, repetitive scoring using detailed questionnaires is burdensome for both the subject and observer, thus reliability may need be conceded for the pragmatic appeal of questionnaire brevity.

Notwithstanding the above challenges, the biggest test of confidence for users of psychometric instruments of dyspnoea in accepting what these instruments purportedly measure is beyond psychometrics. User confidence in a symptom-rating instrument cannot be wholly gained from calculating its validity and reliability coefficients. COPD

patients across the world are known to largely underestimate their symptoms. While assessing subjects' perspective in the Confronting COPD International Survey, it was found that 36% of patients describe their symptoms as being mild to moderate, despite being 'too breathless to leave the house' on the mMRC scale.[16] Likewise, in the COPD MIRROR study, the majority of patients expressed not being completely frank with their doctors during consultation visits, and doctors seem to recognize but underestimate this issue.[17] Accuracy of instruments for rating dyspnoea based on self-reports and questionnaires are therefore universally subject to patients' comprehension, cooperation and truthfulness.

THE UBIQUITOUS MODIFIED MEDICAL RESEARCH COUNCIL SCALE

The most widely utilized instrument for rating dyspnoea is the mMRC scale and it deserves greater explication here. Owing to its simplicity and brevity, clinicians around the world have found it convenient for use as a basic record and classification of dyspnoea severity among COPD patients. The original Medical Research Council (MRC) dyspnoea scale was described by Fletcher in 1952 and consisted of five clinical grades of breathlessness for patients with emphysema, based on their ability to perform physical activities.[18] The usefulness of the MRC scale as a measure of disability in COPD patients have been demonstrated, though not for those with grades 1 or 2.[19] The modified version of this scale that is used today grades patients from 0 to 4, has more simplified statements and refers to "people" instead of "men", but is based on a similar five stages of breathlessness due to physical exertion. It is noteworthy that most MRC grades contain two different activities, but neither the validity of such combinations nor the equivalence of the two combined activities has ever been tested. For example, mMRC grade 1 describes a patient who reports being breathless when hurrying on the level or when walking up a slight hill. From the perspective of COPD patients, this might reflect a relatively less symptomatic individual than others with the condition; but if the scale was used in a healthy population, being breathless when hurrying on the level indicates a significant level of symptoms that likely has an impact on normal daily activities.

The mMRC scale correlates well with heath status[20] and functional status as mentioned above, and together with other parameters - spirometry, body-mass index and exercise capacity, form an accurate predictor of survival,[21] exacerbation risk and hospitalization[22] in COPD. The Global Initiative for Chronic Obstructive Lung Disease (GOLD) guidelines for initial pharmacotherapy in stable COPD recommends that symptoms be assessed in clinical practice by using either the mMRC dyspnoea scale or the COPD Assessment Test (CAT).[23] Since there is some concern about the interchangeability between these 2 instruments especially regarding the recommended 'cut-offs' in classification of severity,[24] it seems rational to use the dyspnoea scale instead of the more global symptom score if the clinician wishes to focus treatment on alleviating the most vexing symptoms that affect patients (as expressed by patients themselves) – dyspnoea and exercise limitation.[25] A more recent study affirmed the use of mMRC scale over CAT in the classification criterion for symptom assessment in the GOLD ABCD system[23] if the focus is on limitation of physical activities in COPD as the mMRC scale better differentiates the physical activities of daily living from sedentary behaviour.[26]

Despite the ubiquity of the use of mMRC scale in scoring dyspnoea intensity in daily clinical practice, the mMRC scale is less useful for comparing outcomes of interventions, as it is limited by its scaling (five-points instead of a minimum of seven for precision as on a Likert scale). Based on scientific evidence, Pulmonary Rehabilitation (PR) is the most effective modality in improving dyspnoea and exercise tolerance in COPD,[27] and when comparing symptom measures as outcomes of this intervention, it appears that the mMRC scale stands at a disadvantage compared to its peers, requiring a 2 unit change as the minimal clinically important difference (MCID), versus the Borg, VAS, BDI/TDI, and Numerical Rating Scale which require smaller changes from baseline to constitute the MCID.[28] As any clinician will know, requiring a $\geq$ 2 unit change in the mMRC as the cut-off point for distinguishing significantly less breathlessness is a huge demand for any current intervention in COPD management to meet. Nonetheless, the BDI is a lengthier instrument and requires interviewer-administration and thus, is mainly used in clinical trials. Despite widespread use of the mMRC scale and the BDI, correspondence of these 2 methods is suspect and there is data to suggest that they explore the dyspnoea intensity differently in COPD patients and are not interchangeable.[29]

Back to the future in physiology?

Of the 3 imperatives for measuring dyspnoea in clinical practice outlined by Mahler and Wells,[1] rating of dyspnoea for establishing efficacy of therapy appears to be the least accomplished through the decades. The absence of a universally accepted measurement tool vitiates against progress in developing novel therapies for relief of dyspnoea. There is currently no instrument

measuring dyspnoea that is acceptable to the United States Food and Drug Administration (FDA) and there has not been a single intervention that has been approved by the FDA for the treatment of dyspnoea *per se*. Both these observations are testament to the inhibition of therapeutic progress due to a failure to measure dyspnoea adequately. In a recent Critical Path Innovative Meeting,[30] the FDA remains non-committal in ever approving a treatment for the 'relief of dyspnoea' in the absence of an adequate and universal measurement tool. Developing and validating additional questionnaires sensitive to changes in both sensory and affective components of dyspnoea or dyspnoea domains specific to COPD is probably not the answer to defining empirical therapeutic efficacy of dyspnoea-relieving treatments as some have suggested[29,30] but instead, paradigm shifts away from psychometrics to the more objective field of physiology appear to be necessary.

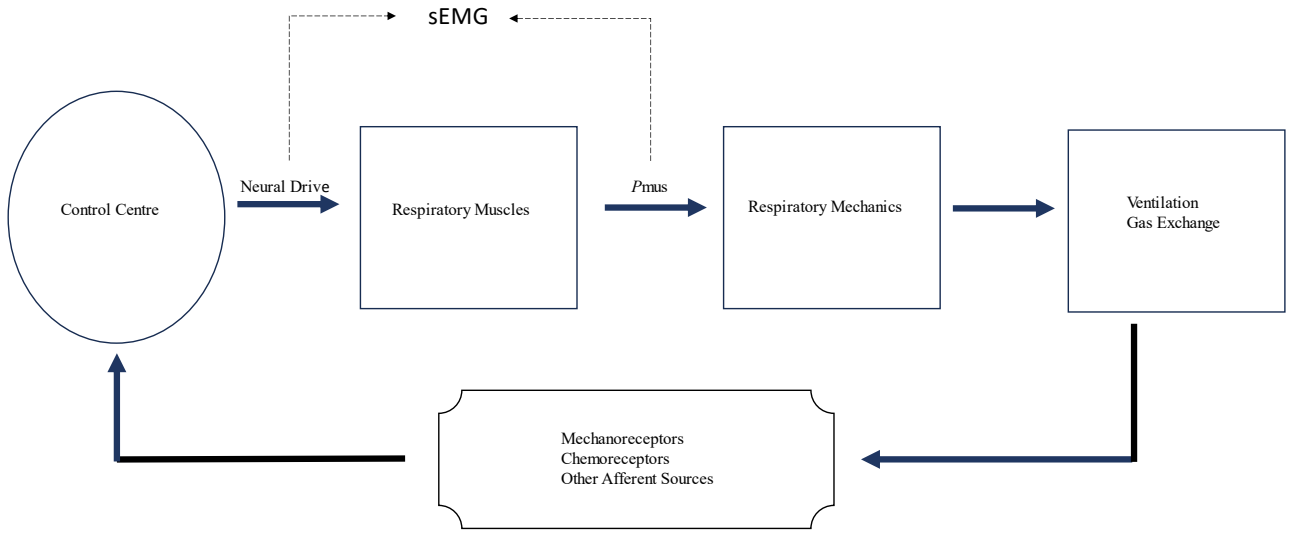

Figure 1. Simplified Illustration of the Respiratory Control Feedback Loop. Dashed arrows represent signals that may be measured by using sEMG

Simply put, respirologists are more at home with respiratory physiology than psychometrics since pulmonary function tests and respiratory equipment in clinical use are largely based on human physiology. However, clinical pulmonary function testing has tended to focus predominantly on lung mechanics and ventilation. Figure 1 illustrates that the entire respiratory system, which consists of a larger feedback loop than the lungs and respiratory muscles. Measures of pulmonary function such as spirometry, lung volumes, and intrathoracic pressures and gas transfer are standard practice while the rest of the afferent and efferent pathways in the respiratory system remain largely untested clinically. Accordingly, in evaluating dyspnoea, a qualitatively complex sensation that involves and is influenced by higher neuro-psychological inputs, clinicians have been limited to subjective, i.e., psychometric tests, while mainstream lung function testing has concentrated on assessing the work of the efferent pathways of the respiratory system. With recent scientific progress especially in the understanding and evaluation of respiratory neural drive, the 'excluded middle' between psychometric evaluation and respiratory physiology may presently be explored for the measurement of dyspnoea in clinical practice.

RESPIRATORY FUNCTION AND EXERCISE TESTING IN EVALUATING DYSPNOEA

Static and dynamic lung function tests are widely used to evaluate the patient who complains of dyspnoea, entailing a combination of psychometric and physiological testing. In Mahler and Wells' study, for example, the authors correlated the self-rated tests with spirometry values, and maximal mouth pressures in patients with chronic lung disorders including COPD.[1] Although significant correlation between dyspnoea ratings and pulmonary function tests may be shown, it is widely known that the two cannot be substituted for each

other.[31] Exercise testing may fare better at evaluating activity-induced dyspnoea, with lung function indices like maximal breathing capacity known to vary during peak exercise from resting values among patients with COPD.[32] Comprehensive cardiopulmonary exercise testing can accurately assess the global process involved in oxygen uptake during exercise and differentiate between the various causes of dyspnoea and exercise limitation in an individual patient. In particular, the cause, severity, and responses to therapy of lung parameters like airflow limitation and dynamic hyperinflation can be assessed directly and non-invasively in COPD patients. However, this test requires considerable costs, expertise, patient cooperation and is limited in availability.

Different types of exercise tests are also known to portray differential data on COPD patients' exercise capacity and responses to physical training.[33] The most widely used exercise test, the six-minute walk test, is a self-paced test, and dyspnoea ratings during the test are pointless for inter or intra-subject comparisons. A submaximal fixed-intensity form of exercise testing may be the best option for quantifying and comparing dyspnoea induced by exercise but this approach is deemed impractical for widespread clinical use.[30] Even for a specific intervention like PR for COPD patients, there are no standardized methods for evaluating changes in physical activity or activities of daily living (ADL) so that the effect of PR on these outcomes cannot be adequately analysed.[34]At present, there is no consensus for standard fixed-intensity exercise testing in chronic heart and lung patients and it appears that there will not be any in the near future.[35]

RESPIRATORY NEURAL DRIVE

As illustrated in Figure 1, the neural drive from the respiratory centre to the inspiratory muscles of the respiratory 'pump' represents a coordinated neural signal in response to all the afferent inputs of the respiratory control system. This neural signal should theoretically correlate with the degree of dyspnoea experienced by a subject, and thus provide a direct and contemporaneous measure of the dyspnoeic sensation, as dyspnoea intensity is accounted for by an awareness of increased respiratory neural drive. The respiratory neural drive can be measured indirectly using diaphragmatic electromyography (EMGdi) as well as electromyography (EMG) of other obligatory inspiratory muscles.[36] This efferent neural signal, also known as the inspiratory neural drive (IND) is typically measured by the EMGdi, as the diaphragm is known to provide about 70% of the force of respiration in healthy subjects. Indeed, the ratio of EMGdi during tidal breathing to the maximal volitional value (EMGdi/EMGdi, max) provides the strongest correlation with dyspnoeic sensation in human studies.[36] The IND therefore represents a physiologic quantifiable parameter that is closely correlated to level of dyspnoea in healthy individuals and those with COPD,[37] and provides a better biomarker of the sensation of dyspnoea than an index of neuroventilatory uncoupling - tidal volume during exercise as a percentage of predicted vital capacity.[38] The major issue against the use of EMGdi in clinical practice is that EMGdi is usually measured with an oesophageal catheter containing multiple paired electrodes, and thus confined to the research laboratory or the intensive care unit, where IND may be used to improve patient-ventilator synchrony or auto-regulate mechanical ventilation. In recent years, advancements in technology of surface EMG (sEMG) have generated widespread interest and introduced the potential utility of sEMG for outpatient respiratory monitoring. sEMG may be defined as EMG of which recording electrodes are placed in contact with the skin overlying or near the muscles of interest as opposed to intramuscular EMG which is invasive. Some major developments in the field of sEMG with regard to respiratory monitoring are summarized below.

SURFACE RESPIRATORY ELECTROMYOGRAPHY – A NON-INVASIVE MEASURE OF INSPIRATORY NEURAL DRIVE AND RESPIRATORY EFFORT

The commonest muscles of respiration that are used for sEMG monitoring are the diaphragm, parasternal muscles, sternocleidomastoid and scalene muscles. The recording EMG electrodes for the first two are typically placed on the 7th – 9th intercostal spaces and the second intercostal space respectively. Correlation between sEMG and transoesophageal EMGdi has been shown to be very high. Wu et al demonstrated significant correlation between transoesophageal EMGdi and surface EMGdi (r=0.966), parasternal EMG (r=0.967), and sternocleidomastoid EMG (r=0.956) in stable COPD patients undergoing treadmill exercise.[39] Lin and colleagues also demonstrated a strong relationship between IND measured by transoesophageal EMGdi percent maximum and IND measured by sEMG percent maximum during incremental inspiratory threshold loading in healthy subjects and in COPD patients undergoing non-invasive positive pressure ventilation.[40] They concluded that sEMG percent maximum serves as a non-invasive marker of neural respiratory drive.

In an earlier study on healthy subjects performing resistive breathing, it was shown that dyspnoea

correlates with transoesophageal EMGdi and transcutaneous sternomastoid EMG until latter stages (when fatigue sets in), beyond which amplitudes of sternomastoid EMG increases but those of EMGdi decreases.[41] From these findings, dyspnoea was thought to be associated with the recruitment of the accessory respiratory muscles rather than the recruitment of the diaphragm.

In recent years, several interesting clinical applications of surface EMGdi in COPD patients have been described. Surface EMGdi was shown to correlate well with parameters predicting the need for hospitalization in COPD patients in acute exacerbation.[42] Parasternal EMG can accurately track clinical change during exacerbations of COPD and predict readmission to hospital.[43] In a larger cohort (n = 120) from the same centre, parasternal EMG was useful as a physiological biomarker of worsening breathlessness and physician-defined clinical deterioration in COPD exacerbations, and may predict early readmission.[44] Potentially, this objective measure can add to the robustness of the current clinical determination of the severity of COPD exacerbations[23,45] as well as more reliably assessing patients on home telemonitoring.[46]

Monitoring of EMG of respiratory muscles can contribute much more beyond what standard lung function and exercise testing modalities currently are capable of. A study highlighting this was one demonstrating that, with minimal change in hyperinflation or pulmonary mechanics, inhaled salmeterol-fluticasone could induce highly significant decrease in activity of the intramuscular parasternal EMG in patients with severe COPD.[47] Although no such study has been performed using surface EMG (to the present author's knowledge), similar studies in larger cohorts seem highly plausible using non-invasive means. Analysis of the amplitude of EMG signals correlate with strength of the muscle being studied, and thus, the amplitude of EMGdi correlates well with respiratory effort.[48] Accordingly, analysis of surface EMGdi signals may also represent a direct and non-invasive measure of muscular pressure (*P*mus), a parameter more commonly determined by its surrogate measure, oesophageal pressure (*P*es), which requires the placement of an oesophageal balloon or catheter.[49] Measuring *P*mus by EMGdi instead of *P*es may be more useful especially in cases with minimal neuroventilatory uncoupling such as in healthy subjects or patients with mild COPD. The clinical applications of measuring respiratory effort non-invasively are immense, and can extend beyond its current indications in the intensive care unit and sleep studies. The recent finding of *P*mus as the parameter that best predicts success of non-invasive ventilation and high-flow oxygen therapy in patients with COVID-19 infection serves to emphasize the need to measure *P*mus, in addition to lung function indices that are more readily measurable such as air flow, airway pressure and tidal volumes.[50]

While amplitude analysis of EMG correlates with strength of muscle activity, analysis of the frequency and time domains of EMG signals can help in detecting fatigue of locomotor and respiratory muscles.[51] For instance, Cavalcanti et al were able to demonstrate that both skeletal and respiratory muscle fatigue contributed to reduced exercise performance in patients with asthma and COPD compared to healthy adults during incremental shuttle walking tests.[52] Thus, sEMG monitoring opens possibilities beyond current standard physiological tests to objectively evaluate troubling symptoms of dyspnoea and muscle fatigue that beset patients with obstructive airways disease.

The utility of sEMG extends beyond the quantification of dyspnoea and respiratory effort in chronic lung disease to non-respiratory conditions. Diaphragm and scalene EMG activity were found to be associated with increasing severity of dyspnoea in acute heart failure patients.[53] The authors of this study remarked that surface respiratory EMG could be a useful objective tool to improve assessment of dyspnoea in patients presenting with acute heart failure.

Although surface respiratory EMG holds great potential, the adoption of this new technology for widespread clinical use will not prove easy. Not least of all a reason for this is that the future use of portable, wearable and preferably wireless EMG recorders for respiratory monitoring requires close cooperation between clinicians and biomedical engineers in their development. A concise summary of the challenges faced in advancement of sEMG in general has been published.[54] Essentially, further technical advancement is required to optimize both the design of the sEMG sensor as well as the algorithms necessary to process the recorded signals. In addition to these general tech developmental issues, respiratory surface EMG development face greater challenges than sEMG used for locomotor muscles.[55] A collaboration between design bioengineers and clinicians is not just ideal – it is essential, as optimization of EMG signal recording and development of algorithms for signal processing require complex arithmetic formulation outside the purview of most physicians. It is heartening to see such research alliances in recent years,[56,57] with clinicians providing the necessary experience in clinical respiratory function

testing and cooperating with technologists in attaining the electro-mechanical correlation that is required for EMG signal conditioning. Currently, no device in development or production has been identified with ready potential for widespread clinical application. Based on the studies appraised in this review, almost all research centres utilize easily accessible EMG sensors and recording equipment, assembled as bespoke set-ups, to conduct their investigation. Only one publication described the use of a commercially available wearable EMG device for wireless surface respiratory recording.[58]

Finally, the most convincing evidence for the potential universal applicability of respiratory sEMG is the recent convention involving expert stake-holders (medical doctors, technical physicians, software engineers and biomedical engineers) focused on developing best practices and overcoming challenges in signal acquisition, processing, and interpretation, with the overall aim of advocating for the generalizability of respiratory sEMG applications from acute intensive care to chronic domiciliary settings.[59] With regard to the challenging clinical evaluation of dyspnoea, a portable surface respiratory EMG monitoring system in the future will be invaluable in assessing the physiological mechanisms leading to dyspnoea during ADL in COPD, determining which interventions are most beneficial when palliating breathlessness, and facilitating the development of patient-reported outcome instruments that quantify dyspnoea based on robust physiological models of breathlessness.[60]

Conclusions

The sensation of dyspnoea is multifaceted and current psychometric instruments used for quantifying dyspnoea in clinical practice may be inadequate, especially for the purpose of optimizing therapy for the relief of dyspnoea. The measurement of respiratory neural drive by EMGdi has been shown to provide a biomarker of exertional dyspnoea that is more sensitive than pulmonary function indices at rest and during exercise in patients with COPD. Further development of surface respiratory EMG portends the provision of an objective and non-invasive measurement of dyspnoea, thus contributing to the current management of COPD and other medical conditions.

Conflicts of Interest Statement: None

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