The relative impact of respiratory muscle activity on tidal flow and lung volume in infants
Hutten, G.J.

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Chapter 2

A literature review of the EMG of the diaphragm

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Abstract

**Introduction:** EMG measurements of the diaphragm (rEMG) provide insight into ventilatory muscle activity. Applicability of these measurements has improved, but literature of the different rEMG measurement techniques is inconsistent. This makes it difficult to compare studies of rEMG technique. This study summarizes the current available literature on rEMG and focuses on the validation of the techniques. Furthermore, we propose to use validation criteria improving the quality, for further research.

**Methods:** Pubmed, Ovid Medline and EMBASE were searched for studies describing rEMG experiments with transcutaneous (tc-rEMG) and/or transesophageal (te-rEMG) methods. Validation criteria included feasibility, repeatability, signal disturbance and ECG gating.

**Results:** 650 studies were eligible for reviewing; 211 were excluded, and 39 articles described the measurement technique and were analyzed according to the criteria. 194 referred to another paper with a description of the technique. 206 failed to describe the technique nor had references to it.

**Conclusions:** Many studies showed neither a description of the technique used, nor a validation of the technique used, or referred to other studies that describe the measurement technique. We propose that future studies on rEMG measurements at least meet the above mentioned criteria, in order to compare study results.
Introduction

Over the last decades electromyography (EMG) has progressed to become a useful clinical test. It records electrical activity within a muscle. This information is used to determine muscle capacity in terms of contractile functions and changes in various situations. In addition to its diagnostic use in neuromuscular disorders, EMG has also been used to measure electrical activity of the diaphragm (rEMG). Using rEMG may help to provide a more comprehensive picture of the control of breathing, since the diaphragm is only one of the components in the generation of the tidal flow wave form. A comprehensive picture of the changes in lung mechanics in disease or exposure to environmental toxins or drugs can only be achieved when lung mechanics are measured in relation to changes in respiratory muscle activity.

In clinical settings rEMG is frequently used in sleep studies and in the field of intensive care. In research, rEMG has proven helpful in providing better insight into breathing patterns in neonates, the control of breathing, and in the mechanism underlying tidal breathing. Moreover, it has been used as a non-invasive tool in estimating lung function in children with asthma, and in adults with COPD.

Three methods are currently used to detect the electrical signal, and each type is useful in specific situations; the transcutaneous method (tc-rEMG) in which the sensors are placed on the skin, the transesophageal method (te-rEMG) in which the sensors are mounted on a catheter, which is positioned in the oesophagus and the intramuscular method (im-rEMG), in which the needle or wire sensors are introduced in the muscle tissue.

Standards concerning practical aspects of rEMG in general have been published, that one needs in mind when reading a rEMG study. The electrical signal of the diaphragm, when measured as tc-rEMG or te-rEMG, is considerably affected by interference of the electrical activity of the heart during contraction. So, each method has pitfalls and results that have been published have led to question the value of such studies.
Diaphragm activity monitoring techniques continue to develop and expand. Future studies will be compelled to be able to compare results between different measurement systems. We hypothesise that most of the studies that have been performed up to now do not adhere to earlier defined standards. We aimed to address the available literature to the following issues: Which methods of rEMG measurement have been used, to what extent adhere the measurement techniques to the earlier defined standards concerning practical aspects of measurement. In addition, we aimed to rate the available literature by category of evidence. Finally, based on these observations, we aimed to propose recommendations for future studies.

**Methods**

*Types of studies*

All studies describing experiments with tc-rEMG and/or te-rEMG methods were included.

Im-rEMG studies were excluded because of discomfort and invasiveness for individuals undergoing these measurements, making the test unsuitable for regular use in clinical settings.

*Type of participants*

Individuals of all ages, with and without disease, were considered for this study.

*Types of outcome measures*

Experiments describing both the tc-rEMG as well as the te-rEMG method were graded separately.

The outcomes were the type of method of rEMG measurement, the description of the technique that was being used, and the quality of evidence.

Papers with a description of the technique were subjected to different criteria which can be divided into general and validation criteria.
General criteria were description of the population that was used in the study, and feasibility and reproducibility of the measurements. Feasibility is defined as the percentage of subjects involved in the research on which the method was applied successfully. Short-term reproducibility was scored when recording instruments were kept in position and experiments were repeated, and when measurements of consecutive breaths were included in the original analysis. Long-term reproducibility was defined as the repetition of the experiment on different occasions. The validation criteria are based on earlier defined standards and apply to the technique of measurement. With respect to the quality of the EMG signal these include a description of ECG interference with the EMG signal, e.g. ECG/QRS gating of the EMG signal, and minimization of the amount of interfering side noise, e.g. movement artefacts.

When case authors referred to third papers containing information about validation of the technique, the reference was accessed and used in the analysis.

The category of evidence was graded according Centre for Evidence Based Medicine, Oxford, scale (www.cebm.net/levels_of_evidence.asp) (Table 1)

Search methods for identifying studies
Pubmed, MEDLINE (1950 – January 2007) and EMBASE (1980 – January 2007) were searched using the search terms ‘electromyography’ and ‘diaphragm’. The search was limited to English papers and human studies.

Methods of review
Each study was independently reviewed by two reviewers. Reviewers were not blinded to authorship, journal or results at the time of review. Evaluation of the papers was performed by GJH an HFvT.

Studies which met the inclusion criteria for the review were evaluated on the presence of a description of the EMG method. Furthermore, we evaluated whether the paper described the quality of the technique that was used. When authors referred to a third paper for technique validation, the referenced paper was used. Fig. 1 shows the scoring algorithm used.
Table 1. Classification of recommendations and evidence

Level of evidence
Ia  Evidence from meta-analysis of randomized controlled trials
Ib  Evidence from at least one randomized controlled trial
IIa Evidence from at least one controlled study without randomization
IIb Evidence from at least one other type of quasiexperimental study
III Evidence from nonexperimental descriptive studies, such as comparative studies
IV  Evidence from expert committee reports, or opinion, or clinical experience of respected authorities, or both

Strength of recommendation
A  Directly based on category I evidence
B  Directly based on category II evidence or extrapolated recommendation from category I evidence
C  Directly based on category III evidence or extrapolated recommendation from category I and II evidence
D  Directly based on category IV evidence or extrapolated recommendation from category I, II or III evidence

When a paper was not lucid on one or more of our score criteria, the reviewers reviewed the paper together and reached consensus as to whether or not to include the paper in the study.
Figure 1)
Flow charts for the analysis of the studies resulting in the level of evidence. For explanation of the level of evidence see table 1.

Results

We identified 493, 628 and 398 studies in Pubmed, MEDLINE, and EMBASE, respectively. All hits in Pubmed where also identified in MEDLINE. The search in EMBASE resulted in 25 studies that were not found in Pubmed. Three studies from MEDLINE were excluded due to duplicate reporting, leaving 650 papers eligible for reviewing and inclusion in the analysis.

Of these 650 studies 211 were excluded because they were inconsistent with the above mentioned inclusion criteria (79 studies described the im-rEMG technique and 132 did not concern rEMG experiments). Of the remaining 439 papers, the level of evidence was scored as follows: 39 studies at level IIb, 194 studies at level III, and 206 at level IV. 238
described the tc-rEMG technique and 176 the te-rEMG technique. In 25 papers both techniques were described.

The 39 papers with a level IIb (the highest scoring level) described the measurement technique and are summarized in Table 2. Of these 39 studies, 14 described the tc-rEMG technique, 18 the te-rEMG technique, and in 7 papers both techniques were described. The percentages of the papers that contained the different validation criteria are shown in Fig. 2.

Figure 2)
The different general and validation criteria expressed as a percentage of the total number of studies with description of the technique.
Table 2. Studies describing the measurement technique

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Signal disturbances and ECG gating were described in 17 (43.6%) and 30 (68.9%), respectively. In 27 papers (69.2%) reproducibility was investigated, in 24 (55.6%) of the papers feasibility was described. The quantity and description of the participants were reported in 38 (97.4%) and 30 (68.9%), respectively.

The 194 papers with level III evidence failed to describe the technique that was used, but referred to third papers. The 206 papers with a level of evidence of IV both failed to describe the technique used and did not refer to a third article.

Discussion

We aimed to summarize the available literature of the different applications of rEMG and investigated whether the used methodology of the rEMG measurements was sufficiently described and validated. Only 39 of the 439 (8.9%) papers that were eligible for reviewing were rated in category IIb “Evidence from at least one other type of quasiexperimental study”. No papers had a higher rating, and the rest of the papers had a lower rating. Signal disturbances and ECG gating was described in 17 (43.6%) and 30 (68.9%) papers, respectively. In 27 papers (69.2%) reproducibility was investigated, in 24 (55.6%) of the papers feasibility was described.

We found that many studies lack a description of the population that was used, and miss general criteria such as feasibility and reproducibility of the technique that was used. Despite earlier validation criteria were defined by the ATS/ERS13, such as description of interference of the EMG signal by movements of the subjects, cross-talk between the QRS complex with the EMG, and description of ECG gating, a substantial amount of the reviewed studies failed to adhere to these standard.

Quality of rEMG measurements

To our knowledge this is the first study that summarizes the available literature of the different applications of electromyography of the diaphragm, and investigates whether the methodology of the rEMG measurement was described and validated. Initially,
rEMG was used in research settings\textsuperscript{51,52}, but has progressed into a diagnostic tool in clinical settings\textsuperscript{30}. Because of its invasiveness and inconvenience for subjects undergoing the measurements, this study does not include im-rEMG, despite that this method being reported to be safe, feasible and reliable\textsuperscript{53}.

A considerable number (194) of papers referred to studies describing technical aspects of EMG measurements. However, none of the papers contains a complete description of all the criteria we have used for this study, such as description of the population, feasibility and reproducibility of the method, and technical information about the measurement technique.

Description of the feasibility of a technique is an important step in the ongoing process, from the use in research settings, towards use in a more clinical setting. Information about reasons for exclusion of subjects or measurements is important for the validation process of a technique, and may be of importance when deciding on whether or not to implement the technique.

The closeness of agreement between the results of the successive measurements obtained under the same conditions, i.e. repeatability, is an important criterion to describe. For rEMG measurements this requires a stable electrical signal, expressed in stable frequency and amplitudes values. Line frequency and movement artefacts greatly diminish the signal quality\textsuperscript{14}. Line frequency is caused by capacitive coupling of the subject’s body, as well as of the electrode cables, to surrounding power lines and mains-powered equipment. Motion artifact voltages result from mechanical disturbances of electrodes, which will result in change in electrode impedances and therefore will cause change in output signal during movements\textsuperscript{17}. Thus, the recognition of possible artifacts is important in analyzing the signal. Ignoring these criteria will affect the rEMG signal results and makes therefore the interpretation of these results less reliable.

The electrical signal of the EMG when measured as tc-rEMG or te-rEMG, is considerably affected by interference of the electrical activity of the heart during contraction\textsuperscript{14-16}. This interference is intense, because the intensity of the cardiac pulse is much stronger than that of the electrical signal of the respiratory muscles, and influences amplitude and frequency parameters of the EMG. Up to now, there is no ideal manner of separating the
ECG and EMG components from the signal have been found. The two methods currently employed for the reduction of the ECG contamination are the gating technique\textsuperscript{15,54} and the (double-)subtraction technique\textsuperscript{16,33,55}. The former technique involves the removal of a section of the EMG signal centered on the QRS complex. The created gate is filled with a running average\textsuperscript{11,15,56}. Two limitations have been recognized with this technique: Firstly, greater proportions of the rEMG signal must be gated with an increasing of the heart rate, and secondly, segments of rEMG activity of particular interest must be discarded if they are contaminated by ECG activity\textsuperscript{55}. The subtraction technique implies the subtraction of an ECG template from the EMG signal of the diaphragm at each occurrence of the ECG waveform\textsuperscript{57}. This technique may not work if the ECG signal is fluctuating\textsuperscript{58}. Until now we have found no consensus on which technique is preferred, and for which purpose.

\textit{Limits of method}

The validation criteria of the ATS/ERS were defined in 2002\textsuperscript{13}, so the question arises whether it is possible to evaluate studies before 2002 with these criteria. This study strives to provide insight in the quality of the tc-rEMG or te-rEMG applications. With this insight it may be possible to increase the quality of the rEMG technique in future research. The rEMG appears to be a promising technique to provide a more comprehensive picture of the control of breathing.

\textit{Conclusions and proposals for future \textit{rEMG} studies in clinical settings}

We summarized the literature on tc-rEMG and te-rEMG measurements and investigated whether the used methodology of these rEMG measurements was described and validated. Furthermore we tried to estimate the level of evidence for each of these applications. We found that most studies lack one or more of the general and/or validation criteria. Only a minority of the studies (8.9\%) scored an evidence level IIb, the rest of the studies had a lower rating. Our observations indicate that there is a need for further validation of the EMG of the respiratory muscles. For the validation process it is important to start with level 1 diagnostics (randomized controlled trials) or validating cohort studies with
homogeneity. The clinical usefulness of the different techniques depends not only on its ability to measure parameters to discriminate between health and disease and to clarify the underlying pathophysiology. Also within-subject reproducibility both within and between test occasions is important. By example, ability to assess repeatability of rEMG measurements in intubated patients is influenced by factors as clinical instability, or the challenge of maintaining stable measurements conditions in the face of changing clinical status. So there is a need for studies which describe parameters to distinguish what constitutes a clinically significant change as a result of disease progression or response to treatment in individual patients or as part of a clinical trial. This leads to a prognostic estimation or a diagnostic category. Furthermore, it seems necessary to come to a consensus on how to reduce the contamination of the rEMG signal by the ECG signal.

Acknowledgements

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