Tout et al., J Diagn Tech Biomed Anal 2020, 9:1
DOI: 10.37532/jdtba.2020.9(1).141

Journal of Diagnostic Techniques and Biomedical Analysis

Research Article

A SCITECHNOL JOURNAL

Electromyography Study of the Contraction of the Scalene and Rectus Abdominis during the Respiratory Cycle in Healthy Subjects

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Received date: April 15, 2020; **Accepted date**: May 04, 2020; **Published date:** May 11, 2020

Abstract

Purpose: Expose the electromyography and spirometry relationship and establish the chronology of the contraction of Scalene and Rectus abdominis which works together in synergy antagonism in physiological breathing.

Methods: 128 electromyographic tests were performed during the respiratory cycle on 43 healthy adults. EMG signals of Scalene, Rectus abdominis were recorded. The breathing was recorded by using a spirometer (vernier®).

Results: The duration of the contraction of Scalene are superior to Rectus abdominis 82% p-value=0.000058, the amplitude of Scalene is superior of Rectus abdominis, p-value=0.000000073. 109 tests of Scalene contraction begin before that of Rectus abdominis (63.74%), p-value=0.000012. RMS is 0.02 ± 0.011 µv for Rectus abdominis and 0.04 ± 0.021 µv for Scalene, p-value=6.76591E-06. Duration of inspiration is 1.25 s ± 0.19, the expiration is 1.04 s ± 0.19. The mean frequency of Rectus abdominis is 54.19 Hz ± 6.35, it is 57.21 Hz ± 7.08 for Scalene, p-value is 9.84081E-08. The median frequency of Rectus abdominis is 51.05 Hz ± 6.51, it is 52.72 Hz ± 6.94 for Scalene, p-value is 0.0098. The muscle fatigue of Rectus abdominis decreased from 60.40 ± 0.45 to 19.98 ± 4.32. For Scalene it decreased from 60.41 ± 0.4 to 23.52 ± 4.41.

Conclusion: There is a synergistic-antagonism relationship between Scalene and Rectus abdominis during respiration. Scalene is a main inspiratory muscle, its contraction is important in amplitude, duration and frequency. Both muscles are fatigable during the inspiratory cycle.

Keywords: Emg signal; Healthy subjects; Muscle synergy; Rectus abdominis; Respiratory cycle

Introduction

During the inspiratory phase of the respiratory cycle, the diaphragm (main inspiratory muscle) and the accessory inspiratory muscles (scalene, SCOM) contract. The rectus abdominis contracts with the other abdominal muscles (transverse, internal and external oblique) thus ensuring an anterior barrier giving a fixed point to the diaphragm (and to the other accessory inspiratory muscles) so that they can, in turn, increase the chest diameters in three dimensions. In case of paralysis of the abdominal muscles, wearing an abdominal compression strap does not improve the pulmonary functions of spinal cord injury patients. Understanding the role of the abdominal muscles during respiratory cycle is important in healthy subjects and it may be an essential step to overcome its deficit in case of spinal cord injury [1,2].

The objective of this study is to highlight the action of the respiratory muscles during the respiratory cycle (measured by electromyography EMG) in the healthy subject and to establish the chronology of the contraction between the scalene (inspiratory muscles) and the Rectus Abdominis (forced expiratory muscle) which functions physiologically in antagonism-synergy during the respiratory cycle [3,4].

Materials and Methods

Population

43 healthy subjects participated in our study, 23 men and 20 women; the average age is 26.47 ± 4.85 years. 41% are smoking and the average BMI is 22.25 ± 1.89 (Table 1). Each participant signed an informed consent form, in accordance with the declaration of Helsinki. The anonymity of the participants and the confidentiality of the data were guaranteed. The university research ethics committee approved this study under the number: USJ -2016-59.

	Age (years)	BMI	Sex
Mean+ SV	26.47 ± 4.85	22.25 ± 1.89	23 M , 20 W
Percentage			53,3% M, 46.7 W

Table 1: Demographic and clinical data of the subjects participating in the study. BMI: body mass index. M: Man; W: Woman; SV: Standard variation.

Inclusion criteria:

• Age between 18 and 35 years' old.

• No physical activity for at least 30 min before carrying out the experiment.

Exclusion criteria:

• Body Mass Index greater than 25 kg m²

• Pathology of the spine

• Neurological disease

• Cardio-respiratory diseases.

Experimental procedure: The placement of the surface EMG electrodes is done following the recommendations of SENIAM (surface electromyography for the noninvasive assessment of the muscle project). The skin was prepared before positioning the electrodes by shaving and cleaning it with alcohol.

Scalene muscle: The electrodes are placed at neck level on the body of the right middle scalene (right side) in the posterior triangle of the neck between the SCOM muscle and the clavicle (Figure 1), the reference electrode is placed at the elbow.

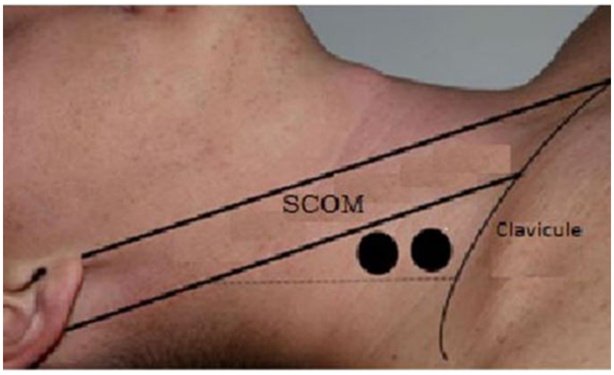

Figure 1: Representation of the placement of the electrodes (EMG) of the scalene muscles on the right [5].

Rectus Abdominis (RA): The electrodes were placed on the muscle body of the RA, (the right side is chosen for all participants), the electrodes were fixed along the muscle fibers at 3 cm above and to the right of the navel with an inter distance 1.5 cm electrode (Figure 2). The reference electrode is placed at the right knee.

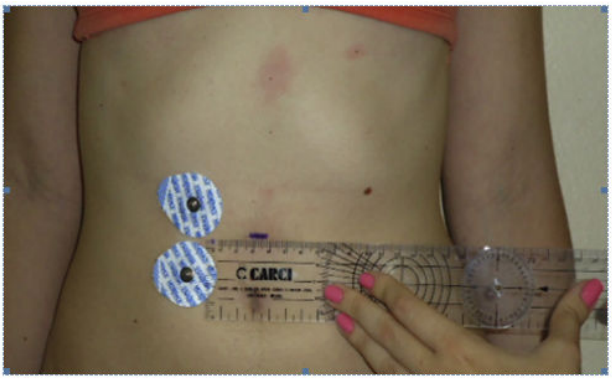

Figure 2: Placement of the electrodes for the RA [5].

Factors affecting the clarity of recorded signals:

Intrinsic factors:

• Skin sweat

• subcutaneous fat layer (at the belly)

• Mobility of the subject during the test

Extrinsic factors:

• Incorrect placement of electrodes

• EMG signal poorly detected especially at the RA level

EMG signal noise processing:

• Bioelectric noise, produced by the biological functions of the subject (heartbeat, breathing), eliminated by a good placement of the electrodes.

• Equipment noise (movement of wires, electrodes, skin and amplifiers) eliminated by the use of high quality electrodes.

• Noise from low frequency cables (10-20 hz) eliminated by filtering at 20 hz.

• External noise: eliminated by diminution of light, cell phone out of service.

In EMG signal preprocessing methods, EMG data analysis is done in the time domain and the frequency domain:

• Temporal analysis: to assess the electrical activity of the muscle as a function of time, to measure the amplitude of the signal, its root mean square or root mean square (RMS) value, its duration and its relationship to other signals [6].

• Frequency analysis: detects signs of muscle fatigue and assesses the power of the EMG as a function of the frequency of the signal: medium frequencies and median frequencies.

Examination protocol: After placing the surface electrodes on the Scalene and RA, the subjects were instructed on how to use the spirometer and how to breathe properly, calmly and loosely at a regular rate. All subjects were asked to place the left forearm on an armrest well-adjusted in height so as to keep the shoulders aligned and in the rest position, the right hand holding the measuring spirometer and the elbow resting on the armrest to ensure maximum comfort for the subject during the test.

The cervical spine is in the straight position of the head in posterior support to minimize the EMG signal relating to the maintenance of the neck and the head by the scalene. The subject should avoid moving of the cervical spine during the test.

The test is stopped in case of spontaneous cough and movement and change of position of the trunk or head. Saving parameters takes 30 sec, followed by a one-min rest. The test was repeated at least 3 times to ensure the good quality of the different measurements before finishing and saving the exam. All tests are recorded and analyzed by Matlab.

Temporal analysis of EMG signals:

Duration of contraction of scalene and RA: The duration of the muscle contraction reflects the number, dispersion and synchronization of activation of the muscle fibers that form a motor unit potential. It extends from the initial deflection of the potential to its final return to the baseline (Figure 3).

The average duration of a muscle contraction is 5 to 15 ms, and it varies depending on the age of the subject and the muscle explored [7].

Amplitude of the RA and scalene EMG signal: The amplitude of the EMG signal illustrates the activation level of a muscle, i.e. the number of active motor units as a function of time. The amplitude of the signal is defined by the voltage difference between the peaks with maximum positivity and negativity. It normally varies between 100 micro volts and 2mv, depending on the number of active fibers present under the surface electrode [8,9].

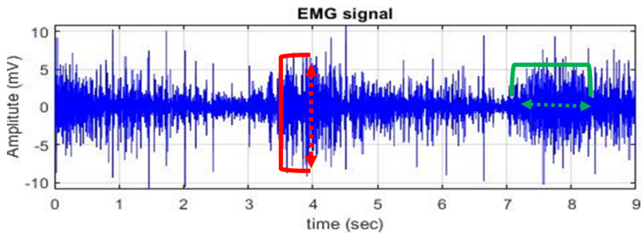

Figure 3: Amplitude and duration of the Scalene EMG Signal. In red: amplitude of the EMG signal, in green: duration of the EMG signal.

Frequency analysis of EMG signals: The frequency analysis is based on the study of well-defined frequency indicators: the median frequency, the average frequency, muscle fatigue [4,10].

Muscle fatigue: It is defined as the increase in muscular, metabolic or psychological cost necessary for carrying out an activity and/or the impossibility of carrying out it. The development of muscle fatigue is generally quantified as a decrease in the capacity of the contractile power of the muscle. The estimation of muscle fatigue by EMG is an important approach because its manifestation over time influences the characteristics of the EMG signal, even before the decrease in muscle strength [11].

Frequencies:

• The median frequency separates the power spectrum into two parts of equal surfaces.

• The mean frequency represents the statistical average of the signal.

Statistical method used: The results are obtained by calculating the mean ± standard deviation. The xlstat 2009 software is used to compare the means by the student test or t-test. A value of $p<0.05$ is considered to be statistically significant.

Results

Evaluation of the duration of the contraction of the EMG signal of scalene and RA

As mentioned before, the scalene muscle is an inspiratory muscle for rest and the duration of its contraction reflects the importance of its active temporal participation in the inspiratory cycle. The objective of this evaluation is to highlight, if possible, the relationship between the contraction of the two scalene muscles and RA during the inspiratory cycle. This may help to assess the actual time activation of these muscles during breathing and the duration of each contraction during the inspiratory cycle [12,13].

The graph in Figure 4 shows the duration of muscle contraction (scalene and RA) in all of the tests. The duration of the EMG signal for scalene is 1.13s ± 0.4 and that of the RA is 0.93 s ± 0.35, the difference being statistically significant (p=1.356e-17) (Table 2).

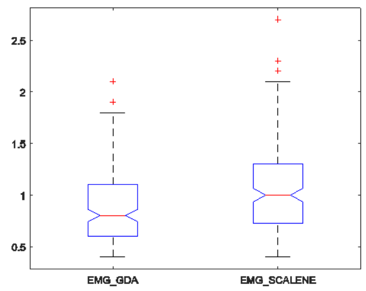

Figure 4: Duration of the RA and Scalene EMG signal (Matlab).

Contraction duration	EMG RA	EMG SCALENE
Mean	0.93 s	1.13 s
Standard variation	0.35	0.4

Table 2: Contraction duration (RA and Scalene).

Evaluation of the amplitude of the contraction of the scalene and RA

The graph in Figure 5 shows the extent of muscle contraction (scalene and RA) in all of the tests performed. The amplitude of the EMG signal for scalene is 0.17 mv ± 0.05 and that of the RA of 0.10 mv ± 0.05 (Figure 5), the difference being statistically significant (p=0.000000073) (Table 3).

EMG signal amplitude	EMG RA	EMG SCALENE
Mean	0.10 mv	0.17 mv
Standard-deviation	0.03	0.05

Table 3: Average of the amplitude of the RA and Scalene EMG signal.

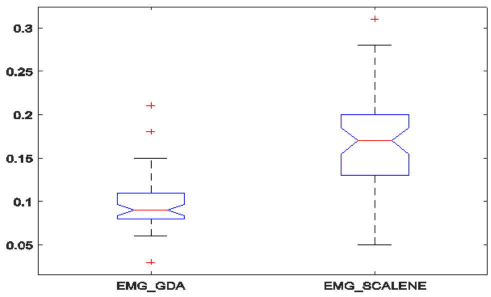

Figure 5: Amplitude of the RA and Scalene EMG signal (Matlab).

Evaluation of the start time of the contraction of the scalene and RA muscles compared to the inspiratory cycle

The boxplot in Figure 6 shows the time relationship between the onset of muscle contraction (scalene and RA) versus the inspiratory cycle in all of the tests performed. The ratio of the start of the EMG signal for scalene to inspiration is -0.47 s ± 0.29 and that of the RA of -0.37 s ± 0.25, the difference being statistically significant (p=1.23202e-09) (Table 4).

Start time of the contraction	EMG RA	EMG SCALENE
Mean	-0.37 s	-0.47 s
Standard-deviation	0.25	0.29

Table 4: Average of the temporal relationship between the inspiratory cycle and the contraction of Scalene and RA.

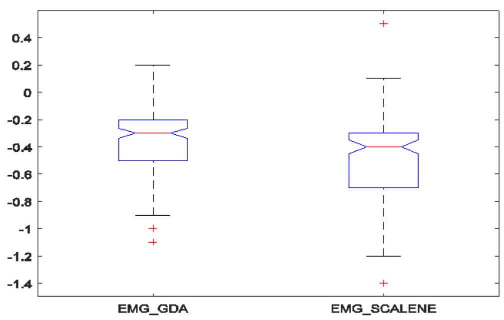

Figure 6: Time relationship between the inspiratory cycle and the contraction of the Scalene and RA muscles.

Evaluation of the time of the end of the contraction of the scalene and RA muscles compared to the expiratory cycle

The ratio of the end of the EMG signal for scalene to expiration is 0.38 s ± 0.25 and that of the RA of 0.38 s ± 0.28, the difference being statistically significant (p=1.56975e-09).

Frequency data analysis of different signals (EMG)

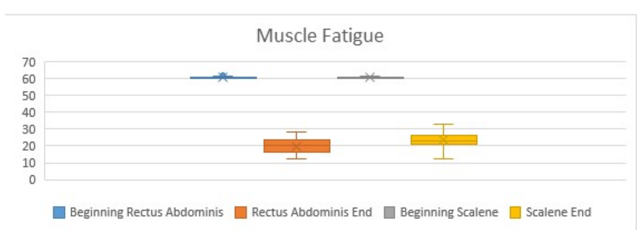

Figure 7: Muscle fatigue (RA and Scalene).

Muscle fatigue: The two muscles, Scalene and RA, participating in the respiratory cycle show a decrease in their ability to produce a force to maintain their concentric contraction during inspiration. However, we note that the Scalene muscle is less tiring than RA and this is related to its ability to produce force for a longer period of contraction. This is in line with the results obtained regarding the duration, amplitude and RMS of the Scalene contraction. The greater the duration and amplitude of the contraction, the higher the RMS value and the lower the value of muscle fatigue (Figure 7).

Discussion

The purpose of using surface EMG is to study the time and frequency sequence of muscle activation of RA and scalene during the respiratory cycle [14,15].

The scalene are active during the entire inspiratory phase, including during calm breathing [16,17]. Their contraction allows the rib grill to expand during inspiration.

The thorax and the abdomen are closely dependent from the respiratory point of view. If the abdominal strap does not resist the thrust of the viscera, they are pushed back lower.

Median frequency: The average RA frequency is 54.19 hz ± 6.35, it is 57.21 hz ± 7.08 for the scalene, with a statistically significant difference (p=9.84081e-08).

Analysis of the temporal data of the different signals (EMG and spirometric)

Duration of contraction: According to the EMG results obtained, the clear difference in the duration and the amplitude of the EMG signal between the scalene and the RA during inspiration and this reflects the clear participation of scalene in inspiration which is more important than that of RA. knowing that RAs are not inspiratory muscles but are synergistic to the diaphragm they have a visceral restraining action which requires less participation in duration and amplitude but which is always present to ensure the increase in chest volumes and l pulmonary expansion on inspiration. The results obtained are in accordance with the biomechanical studies made by De Troyer in 1984 and Kapandji in 1982 in the sense that the RA is synergistic to the inspiratory movement (without making a surface EMG). The duration of the scalene contraction during the inspiratory cycle is greater than that of the RA.

Beginning of contraction of the scalene and RA muscles compared to the inspiratory cycle: Scalene contraction precedes that of RA during the inspiratory cycle in 63.74% of the tests. In other words, the contraction of the scalene is a precursor of the inspiratory movement and in 94.48% of the EMG tests carried out this clearly indicates the significant participation of this muscle in the inspiratory movement which is consistent with the studies done Saboisky et al., in 2007, Gilbert in 1981 and De Troyer in 1994, who found that the scalene are the main inspiratory muscles and which are constantly active throughout the inspiratory phase, including during calm breathing.

Analysis of the frequencies data of the different signals (EMG and spirometric)

Muscular fatigue: Fatigue is defined as the reduction of the muscle's ability to produce force, it is related to a loss of strength and/or time of contraction retention [18].

According to the results, both the muscles, Scalene and Rectus abdominis, participating in the inspiratory cycle are fatigable and have a decrease in their ability to produce a force to maintain their contraction during inspiration. This is consistent with the duration, amplitude and RMS of Scalene contraction. The longer the duration and the amplitude of the contraction, the higher the value of the RMS, the lower the value of the muscular fatigue [15].

It can be concluded that Scalene has an important part of inspiration and its participation gives it the role of a major active muscle in this movement while the Rectus abdominis participates less in terms of duration and amplitude and has a lower contraction capacity and is less resistant to fatigue [19].

Frequencies:

Median and mean: The decrease in frequency (median frequency and average frequency) is linked to the loss of maximum voluntary muscle strength [20]. Muscle strength is proportional to the frequency of discharge. In the tests carried out, there is a significant difference in the average and median frequency between scalene and the RA with a greater value for the average frequency than for the median frequency [21].

Conclusion

This study has shown that scalene is a main inspiratory muscle that contracts from the start of the inspiratory phase. In addition, the contraction of the RA is of small amplitude and the duration is less important as well as the RMS and the mean and median frequency of the EMG signal compared to that of scalene.

Thus, this study made it possible to understand the physiology and respiratory biomechanics concerning two muscles, scalene and RA, as well as the participation of these respiratory muscles by measurement and analysis of EMG signals.

These results can be applied in spinal cord injury patients with total or partial paralysis of the abdominals (reached above t12) in order to correct or alleviate the restrictive respiratory syndrome from which they suffer.

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