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# A linear regression between maximum voluntary contraction and motor unit activity of respiratory muscles during forceful and normal respiration of male athletes using surface electromyography

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## Abstract

The primary objective of this study is to establish a relationship between maximum voluntary contraction (MVC) and motor unit activity (RMS) during forced and normal respiration. Fifty-nine male athletes between the ages of 15-20 years participated. During forceful and regular respiration surface electromyography (sEMG) was performed on participants' external intercostal, diaphragm, and latissimus dorsi muscles. The raw sEMG recordings were filtered to compute MVC and RMS. Pearson's correlation test revealed a substantial positive association between MVC and RMS for all muscles ($p<0.05$). A simple linear regression model was used to establish the best feasible equation based on correlation. MVC shows interconnection with RMS during both respiration in both groups, indicating variations in motor unit activity during respiration may contribute to a muscle's maximum ability to generate force. In these situations, '$y=b+mx$' can be used to quantitatively express the link between MVC and RMS.

**Keywords:** Electromyography, regression, muscle strength, motor unit, respiratory muscles

## 1. Introduction

The recording of the collective electric signal from muscles is known as Electromyography (EMG). It is generated when muscles contract and is governed by the neurological system. In essence, an EMG signal is the electrical activity of a muscle's motor units, and it depicts the anatomical and physiological characteristics of muscles [1]. Non-invasive electrodes or surface electrodes are utilized to record surface EMG (sEMG), which is ideally used to gather data on the timing or intensity of superficial muscle activation [2]. Signals from electromyography (EMG) are thought to be the most practical electrophysiological signals in both medical and non-medical domains. The recording of EMG signals makes it simple to comprehend how the human body behaves under both normal and various pathological circumstances.

The network of tissues and organs that can aid in breathing is known as the respiratory system. It consists of blood vessels, lungs, and airways. The respiratory system's muscles propel the lungs to cooperate in distributing oxygen throughout the body and eliminating waste gases like carbon dioxide [3]. Movements that expand and decrease chest size result in air being inspired into the lungs and then exhaled during the breathing process. Only when there is enough effort to overcome the elastic retraction and airflow resistance is the thoracic movement made possible [4]. Increased neuronal drive to the respiratory muscles results from increased ventilatory demands during exercise. This also affects the muscles' enhanced mechanical power, which is equal to the pressure times the shortening velocity [5].

We may very simply collect extremely valuable information about the neuromuscular activity using electrophysiological techniques [6]. The sarcolemma of the muscle fiber is the location of the bioelectrical source of muscular action. A motor unit is made up of many muscle fibers and an axon [7]. Force is adjusted during voluntary contraction by a combination of motor unit recruitment and variations in the frequency of motor unit activation. The size of a-motor neuron is constantly increased by recruiting its motor unit.

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Surface EMG (sEMG) is a technique to look at the electrical potential of the voluntary muscles without using any force, and as such, it extends the physical investigation and testing of the motor system's integrity [8, 9]. The intensity and duration of muscular activation can also be assessed. For more than 40 years [10], sEMG has been extensively utilized to support clinical diagnosis. It is feasible to assess the muscle activity in the temporal domain of the amplitude of each body muscle independently or collectively to complete the movement [10-12] by using sEMG. One could say that sEMG, also known as kinesiological electromyography, is sometimes used. The ability to collect an electrical signal from a muscle engaged in both static and dynamic movement is provided by electromyographic analysis.

Breathing can be controlled by the brain in either a conscious or unconscious manner [5]. The diaphragm and external intercostal muscles are activated by the phrenic motor nerves' and external intercostal neurons' final output. The operation of the respiratory muscle's motor unit affects how those muscles are controlled through neuromotor influence. Many elements of neuromuscular function and physical performance may be affected by conditions that lead to a reduction in motor unit numbers and changes to motor unit sizes [13]. More motor units are activated by motor unit recruitment to strengthen contractile muscles. More muscle fibers will be activated and muscular contraction will be improved when motor neurons are active [14]. The majority of muscles have a wide range of contractile and fatigue characteristics across their motor units. Many motor activities are made possible by this.

Any muscular activity must have precise and pertinent correlations between the recorded variables for sEMG to evaluate it properly. There are theoretical and mathematical correlations that determine maximal voluntary contraction (MVC) and motor unit activity of respiratory muscles, according to several studies that have been documented. Its alterations and close connection to the respiratory system are utilized to assess lung health. This study revealed a linear link between the MVC and RMS of several respiratory muscles. When all the other predictor variables in the model are maintained constant, this relationship model can be used to determine the relationship between a single predictor variable (motor unit activity) and the response variable (maximum voluntary contraction).

## 2. Materials and Methods

### 2.1 Participants

In this study, fifty-nine (59) male athletes aged ranges from 15-20 years, who were physically healthy and without any physical limitations participated. They received at least two years of training. All of the participants received thorough explanations of the study's objectives and methodology. Every participant was required to sign a letter of prior consent. Following the rules of the Indian Council of Medical Research, prior ethical clearance was also obtained from the institutional human ethics committee (SC/HEC/2019/001 dated 05/07/2019).

### 2.2 Electromyographic recording of different respiratory muscles during forceful and normal respiration

The iWorx IX-214 EMG recorder was set up properly. To record the surface EMG of the diaphragm, external intercostals, and latissimus dorsi, skin-taped silver/silver chloride surface electrodes (8 mm in diameter) filled with conductive paste were placed to clean, abraded skin. Using a spirometer (Schiller SP-1), forceful and normal breathing was performed after the sEMG leads had been placed. All of the muscles' sEMG measurements were taken both during forced and regular breathing.

### 2.3 Electromyographic data recording and analysis

The main variables for analysis are amplitude related i.e. MVC and RMS [15, 16].

- **MVC:** It is the Maximum Voluntary Contraction that means the maximum force generated by the concerned muscle.
- **RMS:** The mean power of the signal is represented by RMS or Root Mean Square. It is used to identify which motor units are involved when a muscle is engaged. It can also be used to look for artifacts and assess signal quality. RMS can be used to assess a muscle's resting level and for biofeedback.
- **Analysis of EMG data:** EMG data were filtered and analyzed using the Labscribe software of the machine (iWorx).

### 2.4 Statistical analysis

The statistical calculations were performed using the IBM Statistical Package for Social Sciences (SPSS) version 24. Mean and Standard deviation (SD) were calculated. At a significance level of 0.05, Pearson's product-moment correlation was used to determine the correlation between the parameters. To establish their association, associated factors were further evaluated using a linear regression model, regression equation, and linear curve analysis.

## 3. Results

The general physical parameters of the participants were represented in Table 1. The mean ± standard deviation (SD) of the electromyographic variables are shown in Table 2 and represented graphically in Fig.1 and Fig.2. The correlation of maximum voluntary contraction (MVC) and motor unit activity (RMS) of the external intercostal, diaphragm and latissimus dorsi muscles of athletes (during forceful and normal respiration) were also represented in Table 2. Positive correlations were found between the MVC and RMS ($p<0.05$) (Table 2). So, linear regression analysis has been done between MVC and RMS in three respiratory muscles i.e. external intercostal, diaphragm, and latissimus dorsi during forceful (Fig 3a, 3b, 3c) and normal respiration (Fig 4a, 4b, 4c). Table 3 shows the R, $R^2$ and adjusted $R^2$ value of all parameters. After analyzing the regression values (Table 3) and regression curves (Fig 3a, 3b, 3c, 4a, 4b, and 4c), linear regression equations were shown in Table 4 accordingly.

**Table 1:** Mean ± SD value of physical parameters of athletes

| Parameters | Mean ± SD value |
|---|---|
| Age (years) | 15.96±2.7 |
| Height (cm) | 166.7±7.05 |
| Weight (kg) | 55.52±8.61 |

**Table 2:** Mean ± SD value and the correlation value of the surface electromyographic activity of the external intercostal, diaphragm, and latissimus dorsi muscles of athletes (male) during Forceful respiration [n=Sample size, r=Pearson's product-moment correlation coefficient]

| **Name of the respiratory muscles** | **Mean ± SD** | | **r** |
|---|---|---|---|
| | **Maximum voluntary contraction (MVC) (mV)** | **Motor unit activity (RMS) (mV)** | **Correlation between MVC and RMS** |
| **During forceful respiration** | | | |
| External intercostal | 1.08±0.42 | 0.24±0.13 | 0.870* |
| Diaphragm | 1.78±0.67 | 0.32±0.15 | 0.867* |
| Latissimus dorsi | 1.38±0.68 | 0.26±0.14 | 0.762* |
| **During normal respiration** | | | |
| External intercostal | 0.61±0.27 | 0.13±0.07 | 0.704* |
| Diaphragm | 1.44±0.56 | 0.25±0.11 | 0.833* |
| Latissimus dorsi | 0.54±0.15 | 0.11±0.05 | 0.356* |
| *Correlation is significant at *p*<0.05 | | | |

**Table 3:** Linear regression analysis between MVC and RMS of three respiratory muscles

| **Name of respiratory muscle** | **Dependant variable MVC Independent variable RMS** | | | | | |
|---|---|---|---|---|---|---|
| | **During forceful respiration** | | | **During normal respiration** | | |
| | **R value** | **$R^2$ value** | **Adjusted $R^2$ value** | **R value** | **$R^2$ value** | **Adjusted $R^2$ value** |
| External intercostal | 0.871 | 0.758 | 0.749 | 0.704 | 0.496 | 0.478 |
| Diaphragm | 0.867 | 0.752 | 0.743 | 0.833 | 0.694 | 0.683 |
| Latissimus dorsi | 0.762 | 0.581 | 0.566 | 0.356 | 0.127 | 0.096 |

**Table 4:** Linear regression plotting between MVC and RMS

| **Group** | **Name of respiratory muscle** | **Dependant variable MVC (expressed as y) Independent variable RMS (expressed as x)** | |
|---|---|---|---|
| | | **During forceful respiration** | **During normal respiration** |
| Male athlete | External intercostal | y = 0.41 + 2.82x | y = 0.26 + 2.69x |
| | Diaphragm | y = 0.53 + 3.89x | y = 0.33 + 4.36x |
| | Latissimus dorsi | y = 0.42 + 3.75x | y = 0.41 + 1.13x |

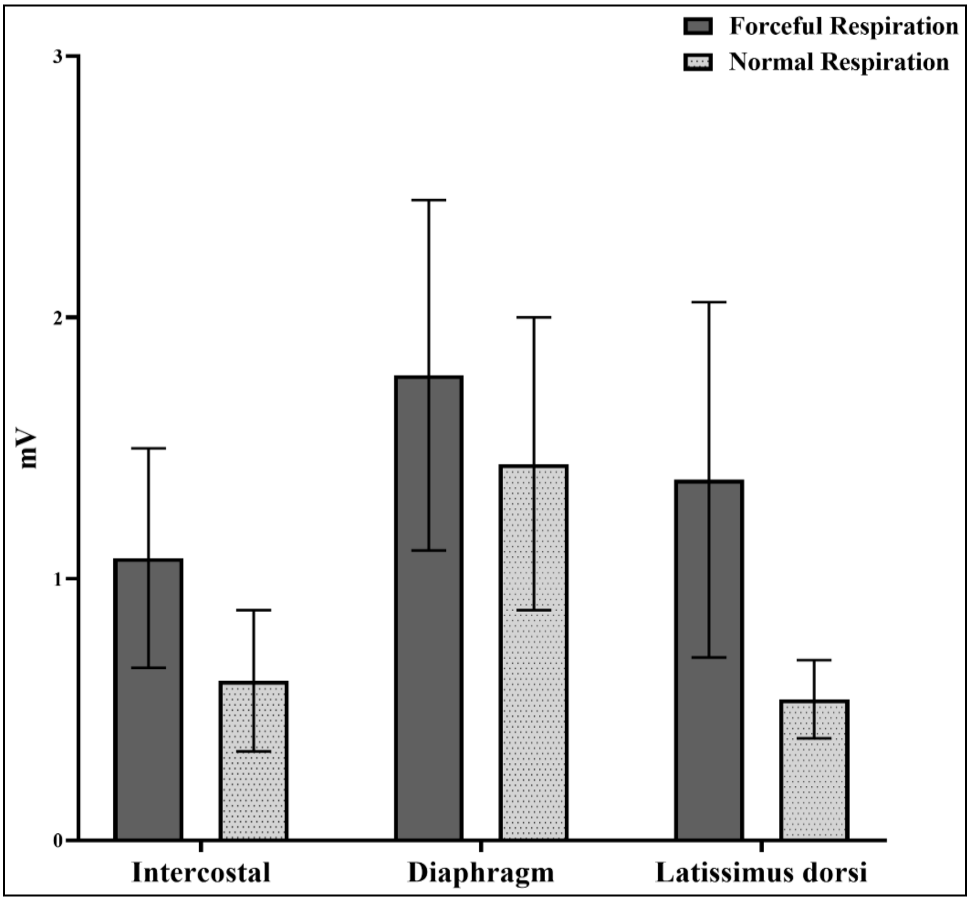

**Fig 1:** Mean ± SD of the Maximum Voluntary Contraction (MVC) of three different respiratory muscles during forceful and normal respiration

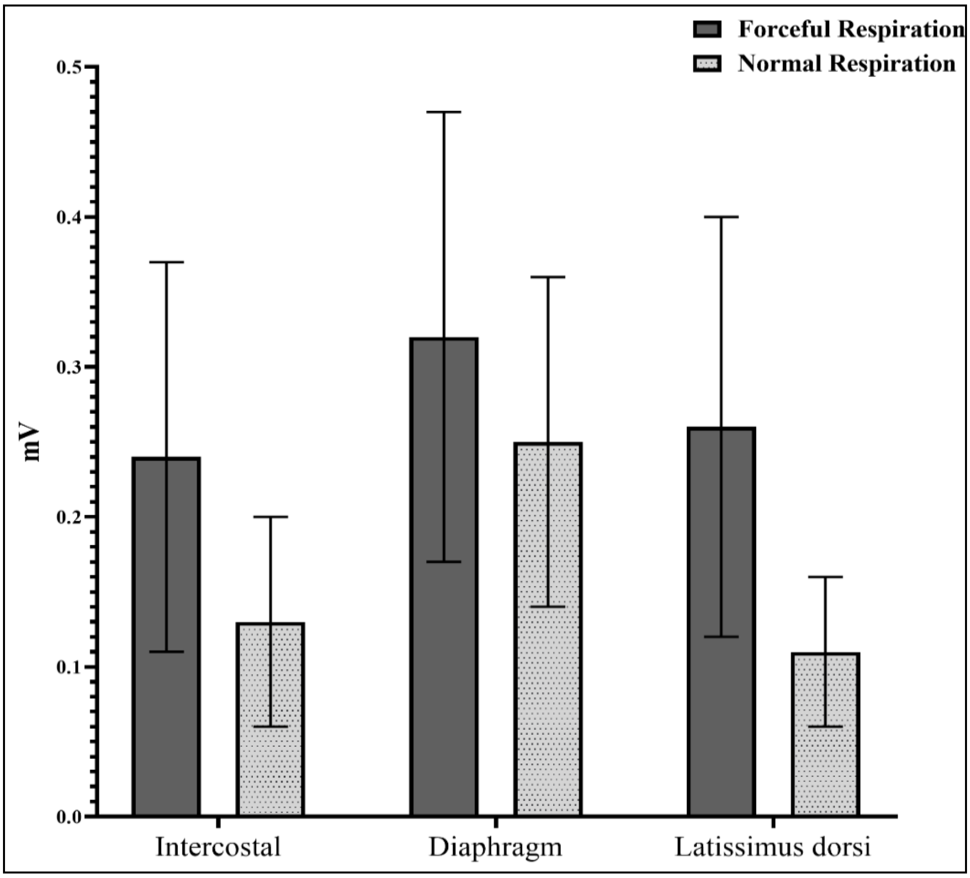

**Fig 2:** Mean ± SD of the Root Mean Square (RMS) of three different respiratory muscles during forceful and normal respiration

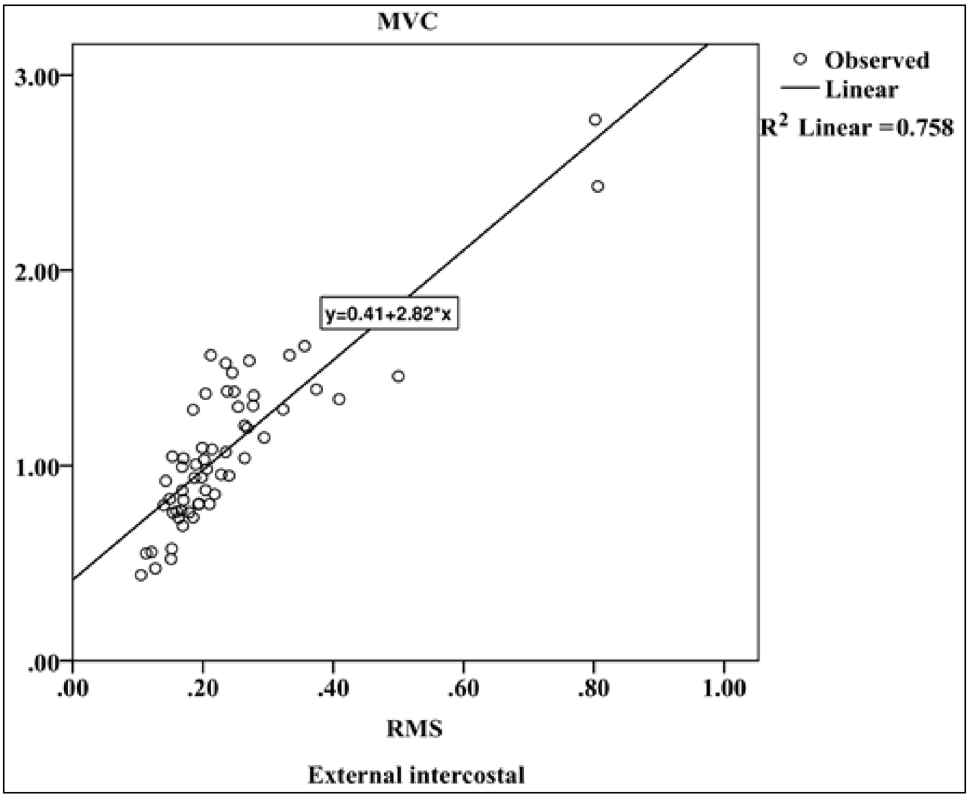

**Fig 3a:** MVC vs RMS regression analysis of External intercostal muscle during forceful respiration

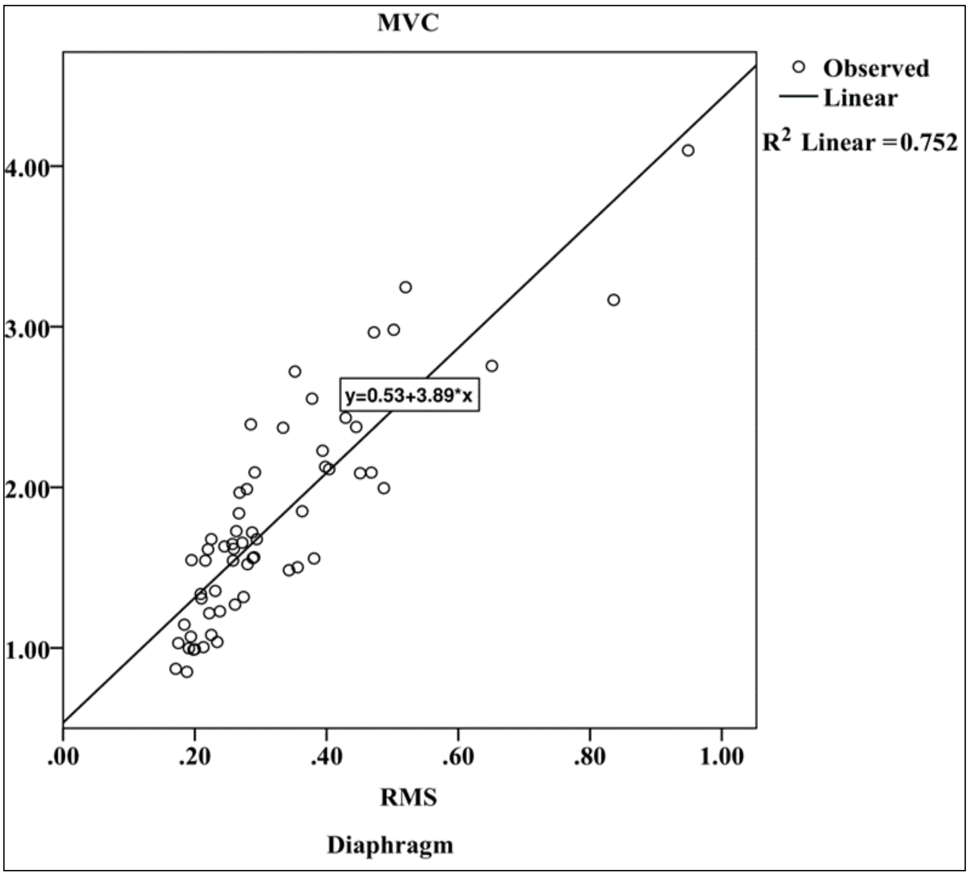

**Fig 3b:** MVC vs RMS regression analysis of Diaphragm muscle during forceful respiration

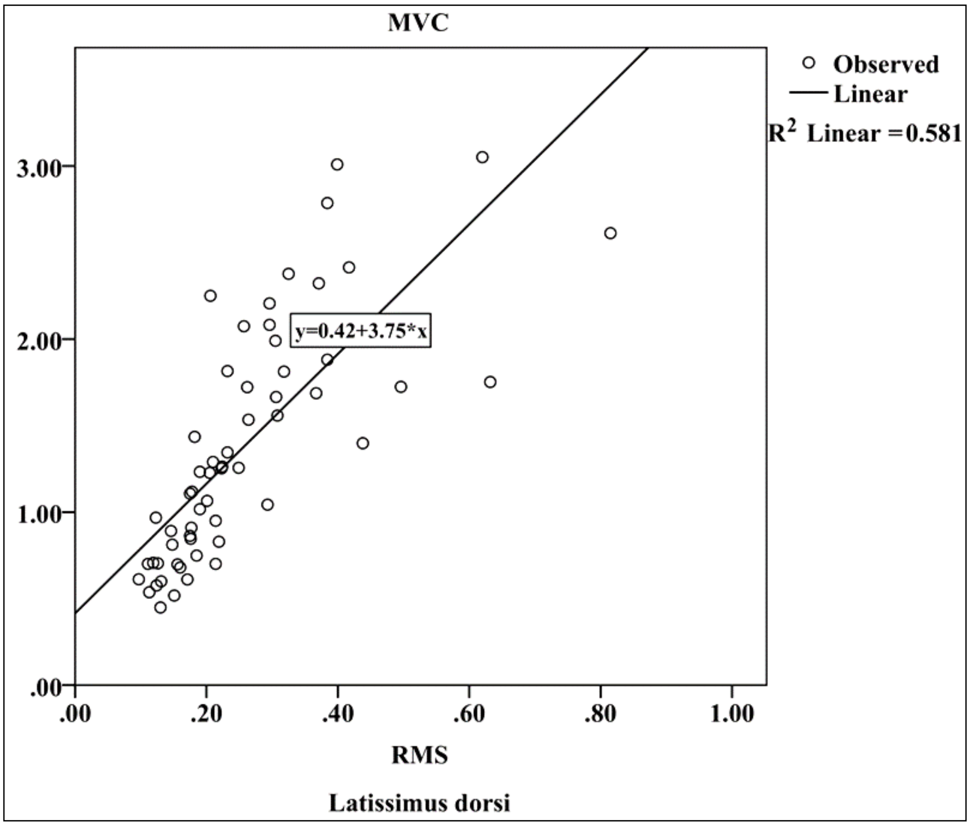

**Fig 3c:** MVC vs RMS regression analysis of Latissimus dorsi muscle during forceful respiration

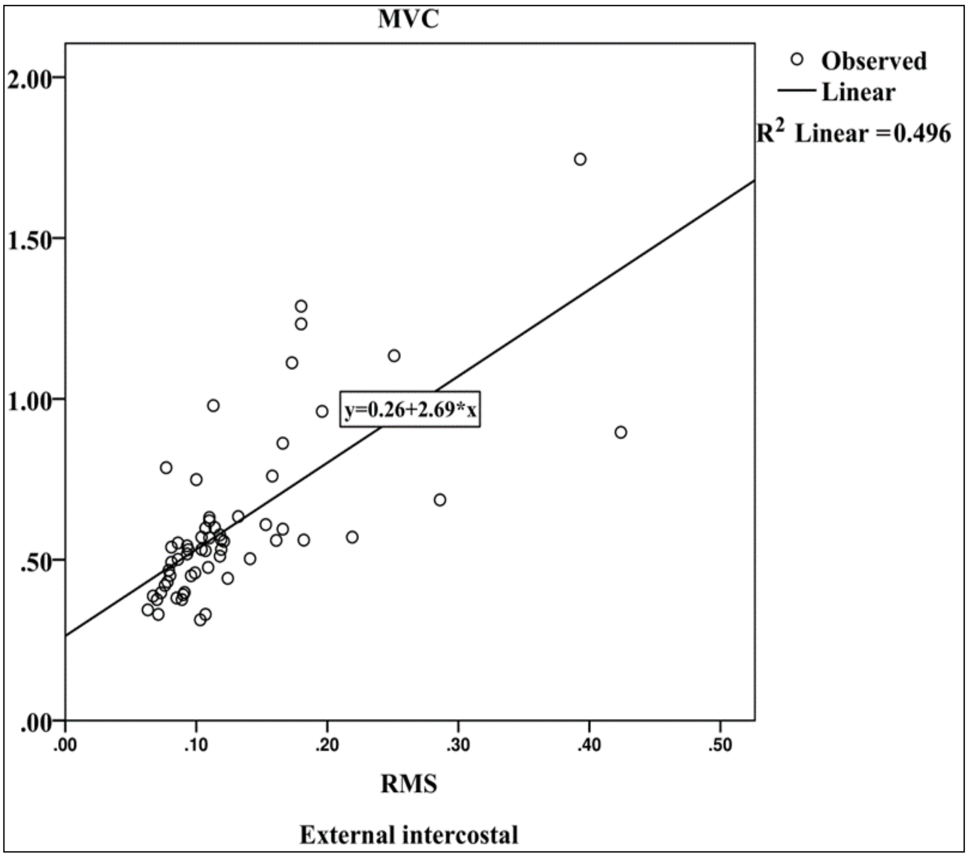

**Fig 4a:** MVC vs RMS regression analysis of External intercostal muscle during normal respiration

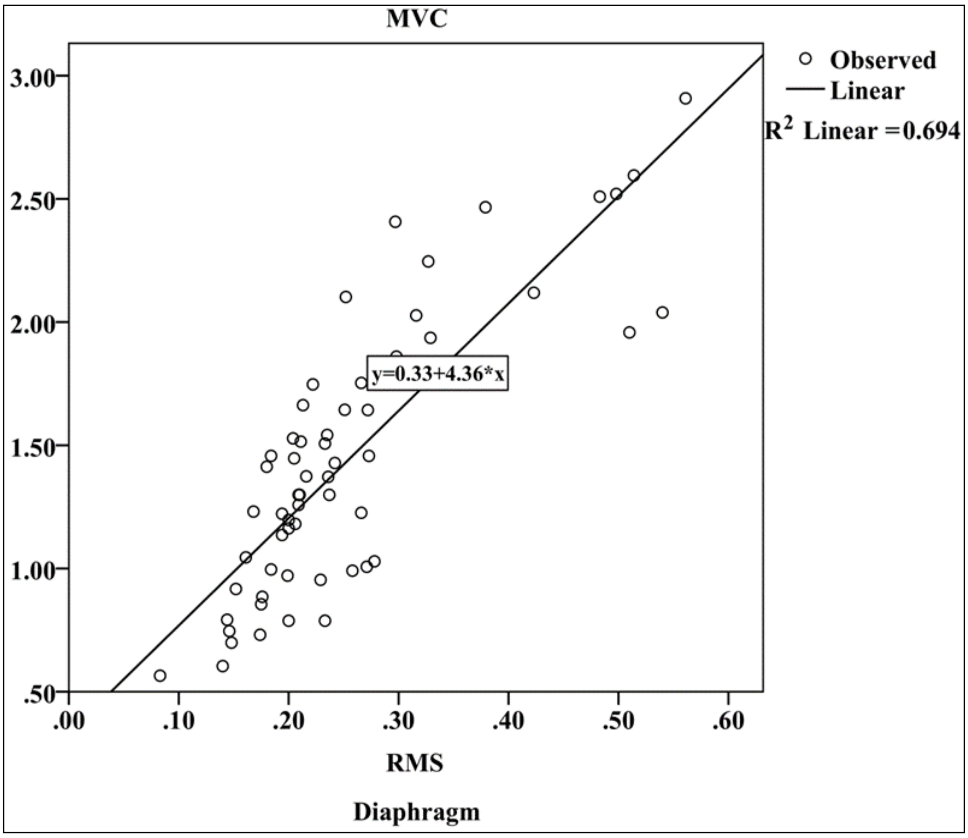

**Fig 4b:** MVC vs RMS regression analysis of Diaphragm muscle during normal respiration

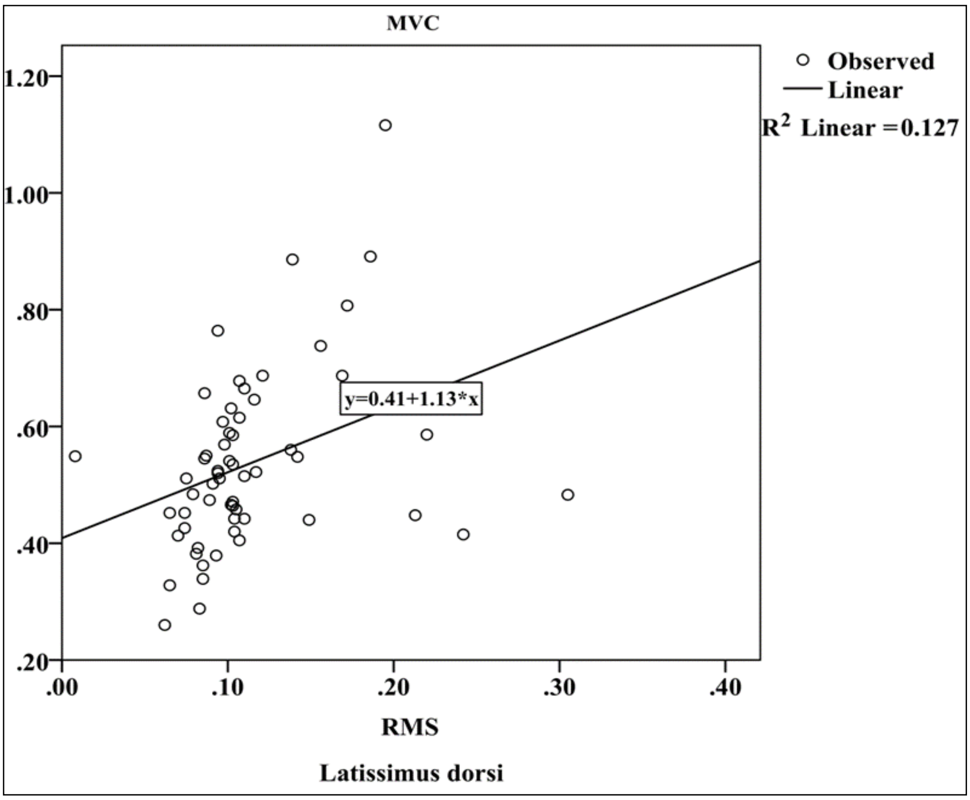

**Fig 4c:** MVC vs RMS regression analysis of latissimus dorsi muscle during normal respiration

## 4. Discussion

Surface EMG (sEMG), which captures the complex motor unit potential produced by the superimposition of several muscle fibers known as the Muscular action potential, can be a useful tool for studying various tasks [17]. The sEMG signal's amplitude and its frequency domain characteristics affect how the signal is measured [18-22]. Henneman's size principle [8], which specifies the link between features of motor neurons and the muscle fibers they innervate and so regulate, are together called motor units. Fast-twitch, high-force, less fatigue-resistant muscle fibers are typically innervated by motor neurons with large cell bodies, whereas slow-twitch, low-force, fatigue-resistant muscle fibers are typically innervated by motor neurons with tiny cell bodies. Motor neurons with small cell bodies are recruited (i.e., begin firing action potentials) before motor neurons with big cell bodies contact a specific muscle.

All fibers within a motor unit have begun to contract once it is turned on. The quantity of active motor units determines the strength of a muscle contraction. Here it is observed that maximum voluntary contraction and motor unit activity is higher during forceful respiration than normal respiration (Fig 1 and 2). Hence, it may be said that more muscle force is required to conduct forceful breathing than normal breathing [23]. Nonetheless, maximum voluntary contraction and motor unit activity is positively and strongly associated in the study group. This shows that elevated motor unit activity contributes to elevating maximum voluntary contraction.

Motor units are recruited in a precise order according to the amount of their force production, with small units being recruited first and displaying appropriate task recruitment, as greater power is required to execute vigorous breathing. In addition, the relative change in force caused by new recruitment remains largely constant, which reduces the degree of weariness [24]. The relationship between MVC and RMS was discovered in this study based on the positive substantial association between them. The value of R-squared ($R^2$) represents the statistical measure of the proportion of the variance for a dependent variable (MVC) that's explained by an independent variable (RMS) in a regression model. Here the strong $R^2$ value of all muscles during forceful respiration represents the regression model is a good fit. The parameters were found to be related by a straightforward linear regression equation (y=b+mx, where y=dependent variable, x=independent variable, m=estimated slope and b=estimated intercept). Understanding the relationship between MVC and RMS during certain respiration is made possible by the regression equation model of various muscles during forceful and normal respiration. This can be easily understood to mean that the appropriate contraction (MVC) of a respiratory muscle depends on the recruitment of how many motor units (RMS).

## 5. Conclusion

Maximum voluntary contraction (MVC) is directly associated with motor unit activity (RMS). This may suggest that variations in the maximal force-generating capacity of a muscle or set of muscles are influenced by changes in motor unit activity. To determine the link between MVC and RMS, a regression equation was created using surface electromyography (sEMG). It is possible to conclude from the analysis of the simple linear regression model that the relationship between the electromyographic variables (MVC and RMS) for the respiratory muscles follows the 'y=b+mx' equation during forceful and normal respiration. This relationship may help future researchers to study a more diverse study or muscle groups to validate these claims.

## 6. Practical implications

A standardized method for determining muscle strength in people with neuromuscular diseases is electromyography (EMG). A single motor neuron and the numerous muscle fibers that its axon connects to are described by the motor unit. Several combinations of active motor units enable a muscle to perform its many distinct responses and voluntary contractions. This investigation aids in determining the condition of the muscles and the nerve cells that regulate the motor neurons in respiratory mechanics. Results from sEMG tests can show issues with nerve, muscle, or nerve-to-muscle signal transmission. To comprehend the intensity and nature of the association between maximal voluntary contraction (MVC) and motor unit activity (RMS) of the respiratory muscles, statistical analysis, in particular the regression equation, was shown here. Here, it is demonstrated how MVC and RMS are interdependent in the case of respiratory muscles. It can be used to estimate the proportionate effects of the predictor variables (RMS) on MVC (the outcome variable). Moreover, the finding of this study can be used as a foundation for future researchers to explore a larger population and even other dominant or accessory muscle groups.

## 7. Acknowledgments

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