Application of Electrical Impedance Principle in the Diagnosis of Diaphragm Fatigue

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Summary: The chest and abdomen impedance respirographs (IRG), including the one dimensional IRG and the two dimensional IRG were designed and produced by applying the principle of bioelectrical impedance. Using IRG the non-synchronized chest and abdomen respiratory motions occurring in diaphragmatic fatigue were measured. The results showed that all 203 normal controls showed synchronized style of chest and abdomen respiratory motions. In 189 COPD patients 117 (61.9\%) showed non-synchronized respiratory motions which could be further divided into three types: type I showed complete contra-directional respiratory movements of chest and abdomen respiration, with M>24 \% and \(\alpha>120^\circ\); type II showed staggered peak of the chest and abdomen motion curves (13 \%<M<24 \%), 50^\circ<\alpha<120^\circ; type III showed double peaks of abdomen trace in the one dimensional IRG and "8"-shaped double circles on the two dimensional IRG, (M<13 \%, 50^\circ<\alpha<120^\circ. When compared with trans-diaphragmatic pressure (Pdi) and diaphragm myoelectricity frequency spectrum, the rates of conformity were 81.8 \% and 90 \%, respectively, suggesting that IRG could be reliably used for diagnosing diaphragmatic fatigue. This technique is simple, easy to use, cheap and pain-free.

Key words: electrical impedance; diaphragm fatigue; COPD

In 1982 Cohen reported that diaphragm fatigue was, perhaps, the most common mechanism leading to respiratory failure with hypercapnia in various clinical conditions and only from that time attention has been paid to it. The techniques commonly used for the diagnosis of diaphragm fatigue include the measurement of trans-diaphragmatic pressure (Pdi)\(^{(1)}\) and the frequency spectrum analysis of myoelectricity\(^{(2)}\). However, these methods are not widely applied in clinical practice for various reasons. In order to find a technique which can be easily used for the clinical diagnosis of diaphragm fatigue, we designed an instrument for measuring the volume changes of both the chest cavity and the abdominal cavity by applying the principle that the volume changes can be reflected by the changes on bioelectrical impedance. The instrument is called impedance respirograph (IRG), which can record the chest and abdomen motion traces simultaneously\(^{(3)}\). By establishing a rabbit diaphragm fatigue model and comparing the results of IRG with Pdi, we found that IRG can diagnose diaphragm fatigue with the sensitivity as high as 81.8 \%, suggesting that it is reliable, to some extent\(^{(4)}\). It is well known that the chest and the abdomen normally move in a synchronized style (phase difference is zero) while when diaphragm fatigue exists this synchronized style of movement can change into a contra-directional style (phase difference occurs). Therefore, diaphragm motion can be observed and its fatigue detected by recording the chest and abdomen motion traces simultaneously.

1 SUBJECTS AND METHODS

1.1 Patients

89 patients in the experimental group were all COPD patients complicated with respiratory failure in our hospital. 143 cases were male and 46 cases were female, with the average age being 63.15 ± 13.3 years. 203 normal subjects served as the control group including 135 males and 68 females with the average age being 59.05 ± 5.1
years.

1.2 Methods

IRG measurements were performed with patients in supine position and under the quiet breathing and the maximum deep breathing status, respectively. Electrodes size was 2.5 cm ± 3.5 cm. The two chest anterior electrodes were placed on both sides of the right mid-clavicular line at the 4th intercostal space level and the two abdomen anterior electrodes were placed on both sides of the mid-abdomen line at the level of 3 cm above the navel. The chest and abdomen posterior electrodes were placed at the position opposite their corresponding anterior electrodes. The distance between two electrodes was 2 cm. Electrodes near the midline served as emitting ones and electrodes away from the midline as receiving ones. All four pairs of electrodes were fixed on the chest and the abdomen with two bandages. The skin should be cleaned and painted evenly with electric conductive paste or with salt water.

The two dimensional graphs were obtained from this instrument, with the X axle being the chest impedance value and the Y axle the abdomen impedance value. We observed the shapes of the graphs, the moving directions, the M value (in two dimensional graph, M value is the ratio of the time interval between maximal X value and maximal Y value (T) to the whole cycle of respiration (C), namely, \( M = \frac{T}{C} \)) and the \( \alpha \) angle (the angle between the line linking \( X_{\text{max}} \) and \( X_{\text{min}} \) and the X axle was an angle. The time between \( X_{\text{max}} \) and \( Y_{\text{max}} \) was \( T \) and one circle time was \( C \). \( M = \frac{T}{C} \). Arrow showed the direction of movement.

![Fig. 1 A: Baseline was 0. The maximal positive wave was +1 and the maximal negative wave was −1](image)

B. Two dimensional IRG with the X axle being the chest impedance value and the Y axle being the abdomen impedance value. The angle between the line linking \( X_{\text{max}} \) and \( X_{\text{min}} \) and the X axle was a angle. The time between \( X_{\text{max}} \) and \( Y_{\text{max}} \) was \( T \) and one circle time was \( C \). \( M = \frac{T}{C} \). Arrow showed the direction of movement.

The frequency spectrum analyses of myoelectricity were performed with the routine technique and the decreases of \( Fc \) and \( H/L \) to 50 % of the baseline value were considered to be the criteria of diaphragmatic fatigue. Exercise test was performed in 23 patients in supine position with cycling ergometer. The work load was 25 kg, two min, and 50 kg, two min. IRG was recorded immediately and 2, 4, 6, 8, and 10 min after exercise.

2 RESULTS

In control group all 203 normal subjects showed synchronized style of chest and abdomen respiratory motion. 117 (61.9 %) different types of non-synchronized respiratory motions were observed in 189 COPD patients (table 1).

None of the 20 subjects in the normal control group showed non-synchronized motions after the cycling exercise. Of the 23 COPD patients with synchronized style of respiratory motion in rest, who performed the cycling exercise, 18 showed non-synchronized motions immediately after cycling exercise which returned to their original synchronized style about 4 min after the exercise. These results suggest that cycling exercise is conducive to detecting latent diaphragmatic fatigue. This phenomenon is also related to the degree of the airways obstruction.

IRG and diaphragmatic myoelectricity were measured simultaneously 30 times on patients and the results showed these two methods gave similar results; most of those with the H/L and \( Fc \) decreases in myoelectricity also had non-synchronized curves on IRG and the conformity rate between these two methods was 90 % (27/30).

Table 2 and figure 1 to 5 summaries the normal graphs and the different types of non-synchronized graphs.