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RESEARCH ARTICLE

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Impact of Abdominal Electrical Stimulation on Restrictive Syndrome in Spinal Cord Injury Patients

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ABSTRACT

Objective: Abdominal Functional Electrical Stimulation (Abdominal FES) is utilized to contract the abdominal muscles using electrical impulses, aiming to enhance respiratory function in individuals with spinal cord injury (SCI). This study seeks to assess the impact of abdominal FES on respiratory function improvement.

Method: Eight spinal cord injury patients from T6 to T12 received abdominal FES for 30 minutes daily over a period of 3 weeks. The intensity of electro stimulation was adjusted at the beginning of each session, with the threshold determined based on the individual's perception of abdominal muscle contraction. The frequency of the current ranged from 15Hz to 20Hz, and the pulse time was determined according to the level and extent of paralysis of the abdominal muscles (total or partial).

Results: Following the 3-week intervention, the average muscle strength of the abdominal muscles increased from 1.875 ± 0.99 to 2.625 ± 1.06 ($p = 0.00253$). The Forced Expiratory Volume in one second (FEV1) improved from 1.41 ± 0.33 to 2.05 ± 0.3 ($p = 0.002305$), and the Forced Vital Capacity (FVC) increased from 1.81 ± 0.39 to 2.50 ± 0.38 ($p = 0.007413$). Additionally, the average Tiffeneau's ratio improved from 0.82 ± 0.1 to 0.71 ± 0.17.

Conclusion: Electro stimulation of the abdominal muscles resulted in a significant enhancement of abdominal muscle strength and improvement in respiratory parameters associated with restrictive syndrome, such as FEV1 and FVC, leading to normalization of Tiffeneau ratio values.

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Introduction

Spinal cord injury (SCI) presents a significant challenge, often resulting in decreased or lost sensation and motor function below the level of injury, along with potential associated organ complications. Among these, respiratory dysfunction is a common and critical issue, characterized by weakened or paralyzed respiratory muscles, diminished vital capacity (VC), and compromised lung compliance, leading to ineffective coughing [1].

Respiratory dysfunction stands out as a prominent medical complication in SCI, significantly impacting patients' quality of life and increasing mortality rates [2]. Its severity varies based on the level and completeness of the spinal cord injury. SCI deprives muscles innervated below the injury of voluntary control, with higher injuries resulting in more extensive paralysis.

Paralysis of respiratory muscles, including the abdominals (T6 to T12) and intercostals (T1 to T6), impairs both inspiratory and expiratory functions. Abdominal muscles play a crucial role not only in forced expiration and coughing but also in synergizing with the diaphragm during inspiration, facilitating optimal thoracic volume expansion [3]. The synergy and antagonism between inspiratory muscles and abdominals are fundamental to physiological breathing [4,5]. However, this synergy is disrupted after SCI and abdominal muscle paralysis above T12, leading to a restrictive syndrome [6,7].

While studies have demonstrated the effectiveness of abdominal muscle electro stimulation in improving cough and expiratory pulmonary functions in SCI, it remains essential to assess its impact on both inspiratory and expiratory capacities and the reduction of restrictive syndrome parameters.

This study aims to evaluate the effect of abdominal muscle electro stimulation on restrictive respiratory syndrome in SCI patients. Approval for this research was obtained from the Saint Joseph University Ethics Committee (USJ -2016-59).

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Methods

Population

Eight spinal cord injury subjects recruited at the Rahme Medical Center during the period from 14/10/2019 and 11/01/2020 participated in a voluntary manner in our experiment and were therefore included in the study.

Inclusion Criteria

• Age between 18 and 40 presenting a restrictive syndrome secondary to spinal cord injury detected by respiratory functional exploration

- Sex indifferent
- Spinal cord injury from C5 to T12 less than 1-year
- Cooperating patient

Exclusion Criteria

- Neuromuscular diseases in addition to spinal cord injury
- Various respiratory or Cardiovascular diseases
- Chest or spinal deformities (scoliosis, kyphosis…)
- Recent surgery (less than 6 months old) of the abdominal wall
- Hyper - sensitivity or hypo - sensitivity to electric current
- Spasticity of the abdominal muscles
- Those who could not bear the application of abdominal electro stimulation or who are impatient to continue all the stages of application and evaluation.

Experimental Protocol

- Assessment of respiratory volumes and flows by a measuring spirometer (Pre-test)
- Assessment of the muscular strength of the abdominal muscles by muscular testing
- Application of the electrical stimulation of the abdominal muscles
- Keep the electrical stimulation for 20 to 30 minutes per session and at the rate of 6 sessions per week.
- Re-evaluation of spirometer measurements and strength of the abdominal muscles at the end of each week.

The electrical stimulation program is applied daily for a duration of 30 minutes from Monday to Saturday. The patient is called upon to breathe calmly. The intensity of the electro stimulation is adjusted at the start of the session and the chosen threshold relates to the specific perception of the muscle contraction of the abdominals and which differs from one person to another. The frequency of the current is 15Hz - 20Hz and the pulse time is chosen according to the level of the spinal cord injury and the extent of the paralysis of the abdominal muscles (total or partial).

The total duration of the application is 3 weeks for each patient, the session is stopped in front of any unpleasant feeling of muscle fatigue or discomfort at the level of electro stimulation. A reassessment is made at the end of the first (Post-test 1), the second (Post-test 2) and the third week (Post-test 3)

Type of Electrical Current

The abdominal muscles, whether totally or partially paralyzed, retain some innervation due to the central and pyramidal nature of the injury. Despite this, they still exhibit reflex contractile function owing to the presence of nerve impulses. In these cases, a rectangular current of short duration is employed for electro stimulation. The contraction frequency is adjusted to prevent muscular fatigue in response to electro stimulation. Additionally, the duration of each stimulation session gradually increases to facilitate better muscle adaptation.

Frequency of Stimulation

A current frequency ranging from 15Hz to 20Hz is utilized to enhance muscular endurance by targeting Type IIa fibers. This frequency range is conducive to longer stimulation sessions, which can extend up to an hour per day. Such prolonged sessions are particularly important in the initial stages of spinal cord injuries to allow for gradual increments in session duration.

Electrode Placement

To ensure comprehensive stimulation of the abdominal muscles, both the transverse muscle (which encompasses the entire abdominal wall) and the rectus abdominis (a powerful anterior muscle) are targeted.

For Stimulating the Rectus Abdominis, Two Electrodes are Positioned on Each Side

- Electrode 1: Placed between the iliac crests and the navel (designated as the green electrode).
- Electrode 2: Positioned at the level of the costal arch to ensure contact with the abdomen and avoid stimulating the intercostal muscles (designated as the blue electrode).
- For the transverse muscle, two large lateral electrodes are positioned between the lower ribs and the anterior superior iliac spine (designated as the orange electrode).

These electrode placements are crucial for effective stimulation and are depicted in Figure 1.

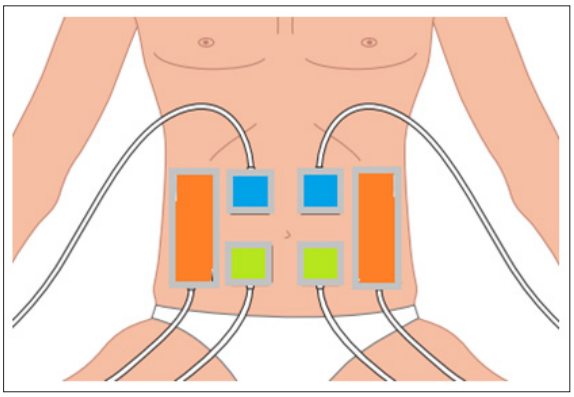

Figure 1: Electrode Placement for Abdominal Muscle Stimulation

Results

The electrical stimulation of the abdominal muscle in spinal cord injured patients permitted an amelioration of the respiratory functions and a diminution of the sign of respiratory restrictive syndrome 3 weeks after the muscle stimulation. The level of spinal cord injury, which results in the degree of damage to the respiratory muscles, is the only significant factor that influenced the end result of electro stimulation.

Muscle Strength

Our results have shown that electrical stimulation of the abdominal muscles of SCI patients induces an increase in the strength of the abdominal muscles. The training of abdominal muscles, following the application of our electro stimulation program, resulted in a significant increase in muscle strength of the order of 15% after 3 weeks of electro stimulation.

The average muscle strength measured, in paraplegic subjects, before the application of electro stimulation (Pre-test), one week after application (Post-test1), after two weeks (Post-test 2) and at the end of the third session (Post - test 3), shows an improvement in muscle strength after electrical stimulation. The mean muscle strength went in pre-test from 1.875 ± 0.99 to 2.625 ± 1.06 in Post-test 3 ($p = 0.00253$). However, we note that muscle strength did not change at the end of the first week, the difference measured at the end of the second week was not significant. (Figure 2).

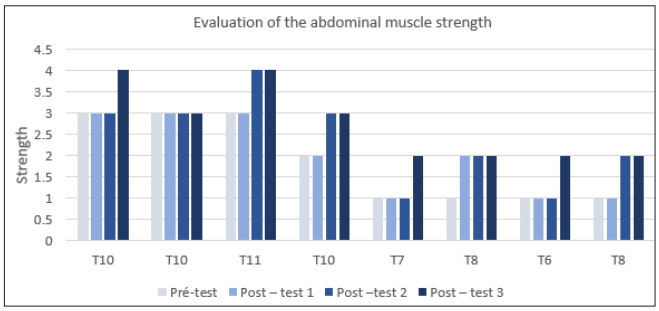

Figure 2: Evaluation of the Abdominal Muscle Strength after Electrical Stimulation

Following this comprehensive assessment of muscle strength in the entire study population, it appears beneficial to divide the patient cohort into two subgroups based on the level of spinal cord injury and the innervation of the abdominal muscles (lesions below T10 versus lesions above T8). No significant difference was observed in muscle strength measurements after electro stimulation at the end of the first, second, and third weeks in the two subgroups.

Evaluation of Spirometer Measurements before and after Muscle Stimulation

FEV1

The mean FEV1 measured in paraplegic subjects before electro stimulation (Pre-test), one-week post-application (Post-test 1), two weeks post-application (Post-test 2), and at the conclusion of the third session (Post-test 3) demonstrates a notable improvement in FEV1 following electrical stimulation. It increased from 1.41 L ± 0.33 in the pre-test to 2.05 L ± 0.3 in post-test 3, with a p-value of 0.002305. However, it's important to note that FEV1 did not change significantly at the end of the first and second weeks of electrical stimulation application. (Figure 3).

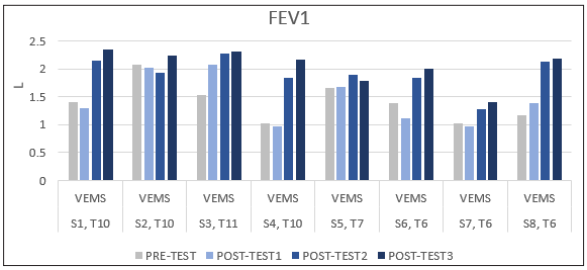

Figure 3: Evaluation of the FEV1 after Electrical Stimulation

The mean FEV1 values in the pre-test and post-tests 1, 2, and 3 do not exhibit any significant differences in muscle strength measurement after electro stimulation at the end of the first and second weeks in both subgroups. However, in post-test 3 and after 3 weeks of electrical stimulation application, there is a significant improvement in the mean FEV1 value, increasing from 1.37 L ± 0.15 to 2.17 L ± 0.23 in the group of patients with spinal cord injury below T10, with a p-value of 0.008.

FVC

The average FVC in subjects with spinal cord injuries, measured before the application of electro stimulation (pre-test) and at the end of the first, second, and third weeks (post-tests 1, 2, and 3), demonstrates improvement in FVC following induced electrical stimulation. It increased from 1.81 L ± 0.39 in the pre-test to 2.50 L ± 0.38 in post-test 3, with a p-value of 0.007413. However, it's noteworthy that FVC did not change significantly at the end of the first and second weeks of electrical stimulation application. (Figure 4).

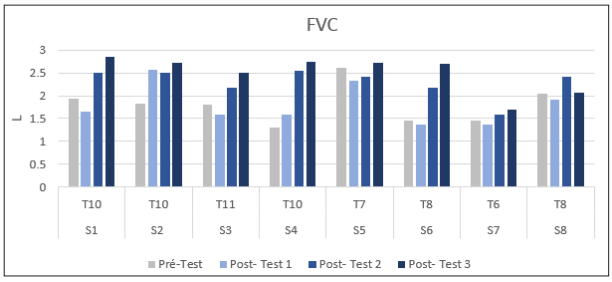

Figure 4: Evaluation of the FVC after Electrical Stimulation

The average FVC in the pre-test and post-tests 1, 2, and 3 shows no significant difference in FVC measurement after electro stimulation administered at the end of the first and second weeks in both subgroups. However, after 3 weeks of abdominal electrical stimulation (post-test 3), there is a significant improvement in the mean FVC value in the group of patients with spinal cord injury below T10. The measured mean increased from 1.72 L ± 0.28 in the pre-test to 2.17 L ± 0.15 in post-test 3, with a p-value of 0.008.

Tiffeneau Ratio FEV1 / FVC

Evaluation of the Tiffeneau ratio FEV1 / FVC reveals no significant difference in the mean ratio in the pre-test and post-tests 1, 2, and 3 after electro stimulation at the end of the first, second, and third weeks in the two subgroups. The mean Tiffeneau ratio changed from 0.81% ± 0.17 in the pre-test to 0.8% ± 0.27 in post-test 1, to 0.81% ± 0.13 in post-test 2, and to 0.82% ± 0.1 in post-test 3. The measured mean of the Tiffeneau ratio, in paraplegic subjects, before the application of electro stimulation (pre-test) and at the end of the first, second, and third weeks (post-tests 1, 2, and 3), demonstrates a non-significant improvement in the Tiffeneau ratio after electrical muscle stimulation.

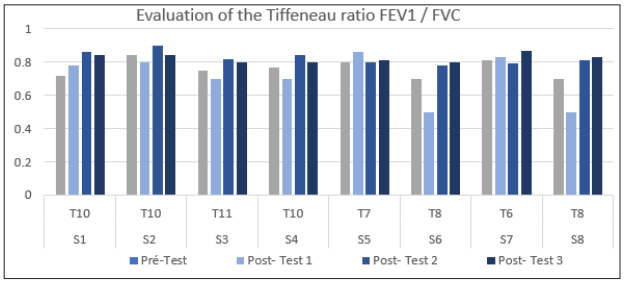

Figure 5: Evaluation of the Tiffeneau Ratio FEV1 / FVC

The mean Tiffeneau FEV1/FVC ratio in the pre-test and post-tests 1, 2, and 3 shows no significant difference in the measurement of the Tiffeneau ratio after electro stimulation at the end of the 1st week, 2nd week, and 3rd week in both subgroups.

The mean Tiffeneau ratio changed from 0.78% ± 0.05 (in the pre-test) to 0.75% ± 0.05 (in Post-test 1), then to 0.86% ± 0.05 (in Post-test 2), and to 0.82% ± 0.02 (in Post-test 3) in the group of patients with lesions below T10. For the group with lesions above T8, it changed from 0.67% ± 0.06 (in the pre-test) to 0.67% ± 0.19 (in Post-test 1), then to 0.81% ± 0.02 (in Post-test 2), and finally to 0.83% ± 0.03 (in Post-test 3).

Discussion

The stimulation of the abdominal muscles in spinal cord injuries enhances the treatment of the restrictive syndrome of spinal cord injuries and their management during the rehabilitation phase.

Abdominal muscles electro stimulation training for spinal cord injuries increases the strength of the stimulated muscle after 3 weeks of electro stimulation. Our results indicate a significant increase in abdominal muscle strength of approximately 15% after 3 weeks of induced electro stimulation, with the mean muscle strength changing from 1.875 ± 0.99 in the pre-test to 2.625 ± 1.06 in Post-test 3 ($p = 0.00253$). This increase was observed in all subjects with spinal cord injuries, ranging from T6 to T10.

These findings align with previous studies by Valli et al. in 2002, Paillard et al. in 2004, and Selkowitz in 1989, which reported gains in muscle strength after electro stimulation training in spinal cord injuries. However, our approach differed significantly in terms of the targeted muscles (abdominal muscles), duration of the experiment (3 weeks), frequency of application (one daily session), and session duration (30 minutes).

Further analysis revealed that the induced stimulation of abdominal muscles in spinal cord injuries led to a significant increase in muscle strength, particularly in the group of patients with lesions <T8. However, one subject (S2), a 24-year-old woman with a T10-level chest fracture, did not experience an improvement in muscle strength following the electro stimulation program. This may be explained by physiological differences, as women typically have fewer muscle fibers than men, resulting in lower overall strength.

Electrical stimulation of the abdominals in spinal cord injuries improves respiratory functions, as evidenced by our results showing an improvement in respiratory function measured by functional respiratory exploration after 3 weeks of training. This finding is consistent with previous studies demonstrating the effectiveness of muscle training in various neuromuscular pathologies.

However, few studies have specifically addressed the effect of abdominal muscle electro stimulation on respiratory signs in spinal cord injuries. Langbein et al. in 2001 showed improvement in expiratory flows and volumes in injuries above T7, but the evaluation was limited to spirometer tests during the expiratory phase.

Conclusion

This study demonstrates the effectiveness of abdominal muscle electro stimulation in increasing muscle strength and improving respiratory signs in spinal cord injuries. Notably, the level of spinal cord damage significantly influences the outcomes of electro stimulation, emphasizing the importance of individualized treatment approaches based on the level of injury [8-36].

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