BREATHING BY FES OF ABDOMINAL MUSCLES IN SCI PATIENTS WITHOUT SPONTANEOUS VENTILATION

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Abstract - *The aim of the study was to find out if functional electrical stimulation of abdominal muscles (FESAM) could maintain pulmonary ventilation at clinically acceptable level in patients with spinal cord injury (SCI).*

Two patients with complete spinal cord injury (C0 and C2level) aged 19 (CW) and 25 (EF) years, on mechanical ventilation for 7 to 12 months, unable to breath spontaneously, were tested.

FESAM was performed with custom-made, battery powered, four-channel stimulator via eight self-adhesive electrodes, sited symmetrically on the trunk in order to stimulate mm. recti abdominis (RA) and lateral group of abdominal muscles (LA). Stimulation was performed in sitting position. Parameters of stimulation: amplitude of stimulus 60-100 mA, stimulation frequency 45 Hz, pulse train duration of 1 sec., breathing frequency of FES artificially activated 20 breaths/min.

Volumes were measured with pneumotachograph. Oxygenation was controlled with pulse oximeter. The limit level of oxygen saturation was 0.92.

The following mean values of tidal volume were achieved in patient CW during one minute of FESAM: RA - 362 m, LA - 577 ml, RA + LA - 816 ml. The average mean value during three minutes of FESAM RA + LA was 513 ml. FESAM of RA + LA in EF patient resulted in 321 ml of tidal volume.

The values of tidal volume measured during FESAM in SCI patients were sufficient to maintain adequate oxygenation during few minutes of duration of stimulation. The results indicate clinical potentials of newly developed FESAM supported ventilation.

Keywords: functional electrical stimulation, abdominal muscles, ventilation, spinal cord injury

1. Introduction

"Conventional mechanical ventilation" refers to the delivery of full or partial ventilatory support by a volume or pressure cycled mechanical ventilator. There are several alternate approaches to mechanical ventilation such as high frequency jet, or airway pressure release ventilation or noninvasive respiratory support aids. In spinal cord injury (SCI) patients the initiation of mechanical ventilation is not a consequence of alterations in lung mechanics and increased work of breathing but the paralysis of respiratory muscles, especially the diaphragm, which is the main muscle of inspiration. With the spinal cord lesion above C2 the patient is ventilator dependent or the ventilation is maintained with phrenic nerve stimulation. In these patients all the work of breathing is overcome with the machine or by stimulating diaphragm muscle. Both methods have limitation of function and quality of living. There are continuous attempts to find comfortable and effective methods of ventilatory support in these patients [1]. Recently more promising results were found with functional electrical stimulation of abdominal muscles (FESAM) [2,3]. By our study we want to find out if FESAM could maintain pulmonary ventilation at clinically acceptable level in SCI patients, not able to breathe spontaneously.

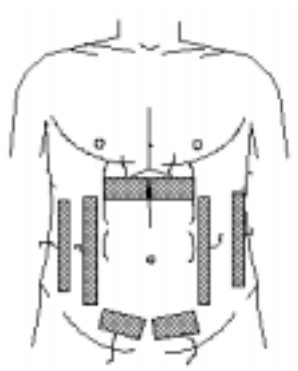
2. Subjects and methods

Two patients with complete spinal cord injury (C0 and C2 level) aged 19 (CW) and 25 (EF) years, on mechanical ventilation for 7 to 12 months, unable to breath spontaneously, were tested.

Stimulation of abdominal muscles was performed with the custom-made electrical stimulator [4]. FESAM was delivered via surface self-adhesive electrodes (PALS Axelgaard, rectangular 5x9 cm) placed on the abdominal wall so that mm. recti abdominis (RA) and/or lateral abdominal muscles group (LA) (mm. transversi and mm. obliqui ext. et int.) were stimulated. For rectus abdominis muscles stimulation, electrodes were placed just below costal margin and above symphysis bone near the median line. For stimulation of lateral abdominal group of muscles, the electrodes were placed parallel to m. rectus abdominis muscle and in the lumbar region. Schematic diagram with the approximate position of

electrodes for stimulation of mm. rectus abdominis and lateral abdominal muscle groups is shown in figure 1.

Figure 1.



Stimulation parameters were: 1 second pulse train at 45 Hz, amplitude of stimulation 60-100 mA, and pulse width 25 µs with fixed breathing rate of 20 breaths per minute artificially triggered by stimulator. Flows were measured with pneumotachograph and oxygenation was controlled with pulse oximeter. Accepted level of oxygenation was 0.92 % saturation. Data was collected with BIOPAC acquisition system. Experiments were performed in sitting position. Duration of FESAM supported ventilation from 1 to 3 minutes in different sessions. In longer sessions the limiting factor was lowering of saturation below 0.92.

3. Results

The mean values of ventilatory parameters during mechanical ventilation and short periods of FESAM during expiration in sitting position for both subjects are shown in table 1. In Figure 2 tidal volume achieved by different abdominal muscles are shown. Figure 3 shows tidal volume of simultaneous FES of RA and LA muscles during prolonged experiment in subject CW. In Figure 4 tidal volume of FES of both groups of abdominal muscles in subject EF at different body postures is presented.

Table 1.

subj.	musc. stim.	Vt FES (l)	Ve FES (l/min)	PEF FES (l/sec)	Vt MV (l)	Ve MV (l/min)
	RA	0,362	7,233	1,463	1,071	9,314
CW	LA	0,577	11,542	1,798	1,046	9,412
	RA +LA	0,816	16,311	2,023	1,093	9,620
EF	RA +LA	0,321	6,42	1,266	0,747	8,9

Vt FES = tidal volume during FES, Ve FES = total ventilation during FES, PEF FES = peak expiratory flow during FES, Vt MV = tidal volume during mechanical ventilation, VeMV = total ventilation during mechanical ventilation.

Figure 2.

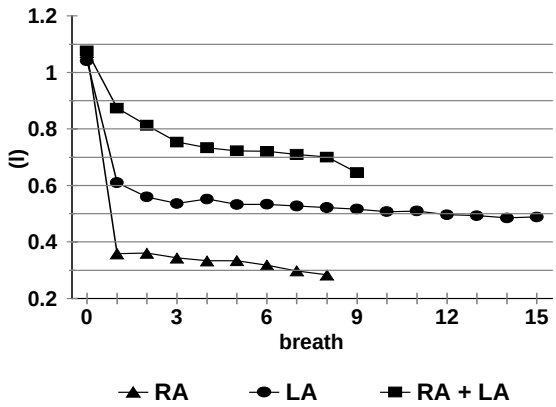


Figure 3.

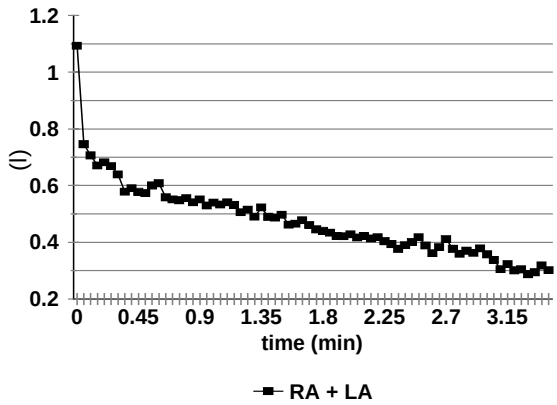
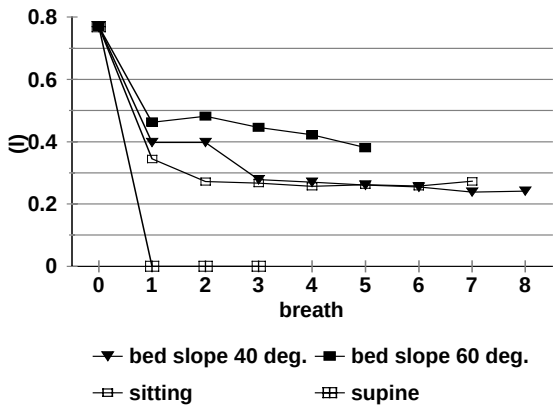


Figure 4.



4. Discussion

The activities of daily living in SCI patients on mechanical ventilation are extremely restricted. The attempts were made to overcome these limitations, e.g.. it was substituted by phrenic nerve stimulation, which also maintains adequate ventilation and enables better mobility of patients.

In our study for the first time the possibility of artificially controlled ventilation obtained by FESAM was experimentally proved. The acceptable oxygenation in SCI patient without spontaneous breathing during 1 to 3 minutes periods was achieved by FESAM only. The previous studies [2,3] showed the augmentation of ventilation in normal subjects and also SCI patients breathing spontaneously, but not in patient dependent on mechanical ventilator.

The differences in combination of muscles used are in accordance to the activity of different abdominal muscle during normal breathing [5]. Although the differences in tidal volume between muscle stimulated are substantial, the alternative mode of FESAM promises the prolongation of controlled ventilation, which could be used in various conditions in SCI patients. In spite of the differences in effectiveness of FESAM generated tidal volume observed in experimental subjects with restrenghtening program the physical endurance of muscles could be increased and fatiguing problems compensated as well [6].

The experimental results proved that the level of FESAM augmented ventilation is body position dependent, better ventilation was achieved in sitting position compared to supine one. In previous FESAM studies in normal subjects and also SCI patients capable of spontaneous breathing the increased values of tidal volume due to FESAM proved to be less position dependent [7].

The newly developed FESAM supported ventilation method indicates high clinical potentials, what should be confirmed in the future studies. Also FESAM technology for prolonged ventilation alone or in combination with mechanical ventilation or phrenic nerve stimulation ventilation should be developed.

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References

[1] Bach JR. Alternative methods of ventilatory support for the patients with ventilatory failure due to spinal cord injury. J Am Paraplegia Soc 1991;14:158

[2] Šorli J, F Kandare, RJ Jaeger, U Stanič. Ventilatory assistance using electrical stimulation of abdominal muscles, IEEE Trans Rehab Engr 1996;4:1-6.

[3] Stanič U, F Kandare, R Jaeger, and J Šorli. Functional electrical stimulation of abdominal muscles to augment tidal volume in spinal cord injury. IEEE Trans Rehab Engr, in press.

[4] Jeraj J, U Stanič, F Kandare, J Jaeger. Four-channel stimulator for expiratory supported ventilation, 6th Vienna International Workshop on Functional Electrical Stimulation, September, 1998, pp. 239-242

[5] Abe T, N Kusuhara, N Yoshimura, T Tomita, PA Easton. Differential respiratory activity of four abdominal muscles in humans. J Appl Physiol 1996; 80:1379-83.

[6] Suzuki J, Tanaka R, Yan S, Chen R, Macklem PT, Kayser B. Assessment of abdominal muscle contractility, strength, and fatigue. Am J Respir Crit Care Med 1999;159: 1052-60.

[7] F Kandare, U Stanič, A Klofutar, R Jaeger, J Šorli, A Pedotti, A Aliverti and G Ferrigno. Lung volume measurements with optical method. Proceedings of 9th International Conference on Mechanics in Medicine and Biology, Ljubljana, 1996, pp. 189 - 192.