

## PULMONARY FUNCTION TESTING IN SPINAL CORD INJURY: EFFECTS OF ABDOMINAL MUSCLE STIMULATION

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### ABSTRACT

The purpose of this study was to assess the effects of applying transcutaneous electrical stimulation to upper motor neuron paralyzed abdominal muscles during pulmonary function testing (PFT) in four male spinal cord injured (SCI) patients with anatomical level of injury between C3 to T7. Patients performed PFTs with and without electrical stimulation delivered to abdominal muscles. The predicted values were computed for comparable nonsmoking neurologically intact individuals based on height and age. The patients with the lowest predicted expiratory volumes and flows demonstrated the greatest improvement when electrical stimulation was delivered during forced expiration. The results indicate that electrical stimulation of the expiratory muscles during forced expiration can significantly improve expiratory volumes and flows in some patients with SCI.

**KEYWORDS:** Pulmonary Function Testing, Spinal Cord Injuries, Electrical Stimulation.

### INTRODUCTION

Expiratory muscle weakness or paralysis in patients with spinal cord injuries (SCI) results in decreased peak expiratory flow rates (PEFR), forced expiratory volume in one second (FEV<sub>1</sub>) and forced vital capacity (FVC).<sup>1,2</sup> Moreover, expiratory muscle weakness or paralysis is responsible for decreased cough efficiency, and contributes to the excess respiratory morbidity in these patients.<sup>3</sup> The purpose of the present study was to assess the effect of transcutaneous electrical stimulation of upper motor neuron paralyzed abdominal muscles in patients with SCI on expiratory flows and volumes. The hypothesis to be tested was that FVC, FEV<sub>1</sub>, and PEFR could be increased over purely volitional levels by applying electrical stimulation to abdominal muscles during the performance of a standard PFT.

### METHODS

**Patients:** Four male patients (ages 29, 29, 40, 58) were recruited from the inpatient and outpatient populations of the Hines Veterans Affairs Hospital SCI Service. The selection criteria included volitional (unassisted) FVC  $\leq$  90% of predicted, anatomical level of injury between C4 and T7, upper motor neuron paralysis of the abdominal muscles, visible abdominal muscle contraction upon application of electrical stimulation, tolerance of the electrical stimulation, and no current pulmonary complaint. The study was approved by the Hospital's Human Studies Subcommittee and written informed consent was obtained from each patient.

**Evaluation of Pulmonary Function:** Lung volumes were measured by timed spirometry. The spirometer software provided predicted values for each patient, based on neurologically intact non-smoking individuals with no known pulmonary complaints (sex, age, and height).

**Electrical Stimulation:** Electrical stimulation was delivered via eight surface electrodes. Two pairs of electrodes were placed on the lower abdomen, near the midline, and

just above the iliac crest. Two other pairs of electrodes were placed on the upper abdomen near the midline, just below the ribs. Spacing between the edges of electrodes was approximately 3 cm. Two standard commercial neuromuscular stimulators delivered a pulse train of 8 s duration. The pulse amplitude was manually set by the investigator, based on visual inspection of the contraction obtained (up to a maximum of approximately 100 mA) and was constant throughout the pulse train. Pulse repetition rate and width were fixed at 50 pulses/s and 250  $\mu$ s, respectively.

Protocol: Patients were studied while seated in their personal wheelchair. Six PFTs were obtained from each patient, alternating methods (volitional only and volitional with electrical stimulation). The trial under each condition with the maximum FVC was retained for analysis. In addition, the two best measurements of FVC under each condition had to be within 5% of each other to be accepted for analysis.

## RESULTS

All patients tolerated the procedure well. No local or systemic adverse effects of electrical stimulation were recorded. Three of the four patients demonstrated a significant enhancement in expiratory flows and volumes (i.e., 10% or greater improvement as compared to volitional PFT), as shown in Table I.

TABLE I: "Best" volume and flow measures and percent predicted values (*italicized values*) for four patients with SCI who completed pulmonary function testing volitionally and with electrical stimulation of the abdominal muscles. Changes ( $\Delta$ ) are presented in **bold** and are the result of subtracting the volitional from the stimulated values.

PATEINT #	FVC (L)		FEV <sub>1</sub> (L)		PEFR (L/s)	
	volitional	stimulation	volitional	stimulation	volitional	stimulation
272 ( $\Delta$ )	1.63 35%	2.62 57% (0.99 22%)	1.55 41%	2.20 57% (0.65 16%)	4.23 48%	5.83 66% (1.60 18%)
294 ( $\Delta$ )	2.43 59%	3.05 72% (0.62 13%)	2.06 62%	2.25 68% (0.19 8%)	4.08 48%	4.92 60% (0.84 12%)
299 ( $\Delta$ )	4.48 77%	5.50 87% (1.02 10%)	4.01 83%	4.23 88% (0.22 5%)	6.62 65%	8.72 86% (2.10 21%)
275 ( $\Delta$ )	5.45 88%	5.51 88% (0.06 0%)	4.75 90%	4.69 90% (-0.06 0%)	8.92 84%	9.07 85% (0.15 1%)

Figure 1 below shows a spirometric tracing from patient # 272 (C 4-5 lesion) for unassisted PFT (solid line) PFT with electrical stimulation (dotted line). Panel A (lower right): volume-time relationship; Panel B (upper left): flow-volume relationship. As compared to the unassisted maneuver, the electrically assisted maneuver produced a 650 ml increase in FEV<sub>1</sub> (Panel A) and a 1.60 L/s rise in PEFR (Panel B).

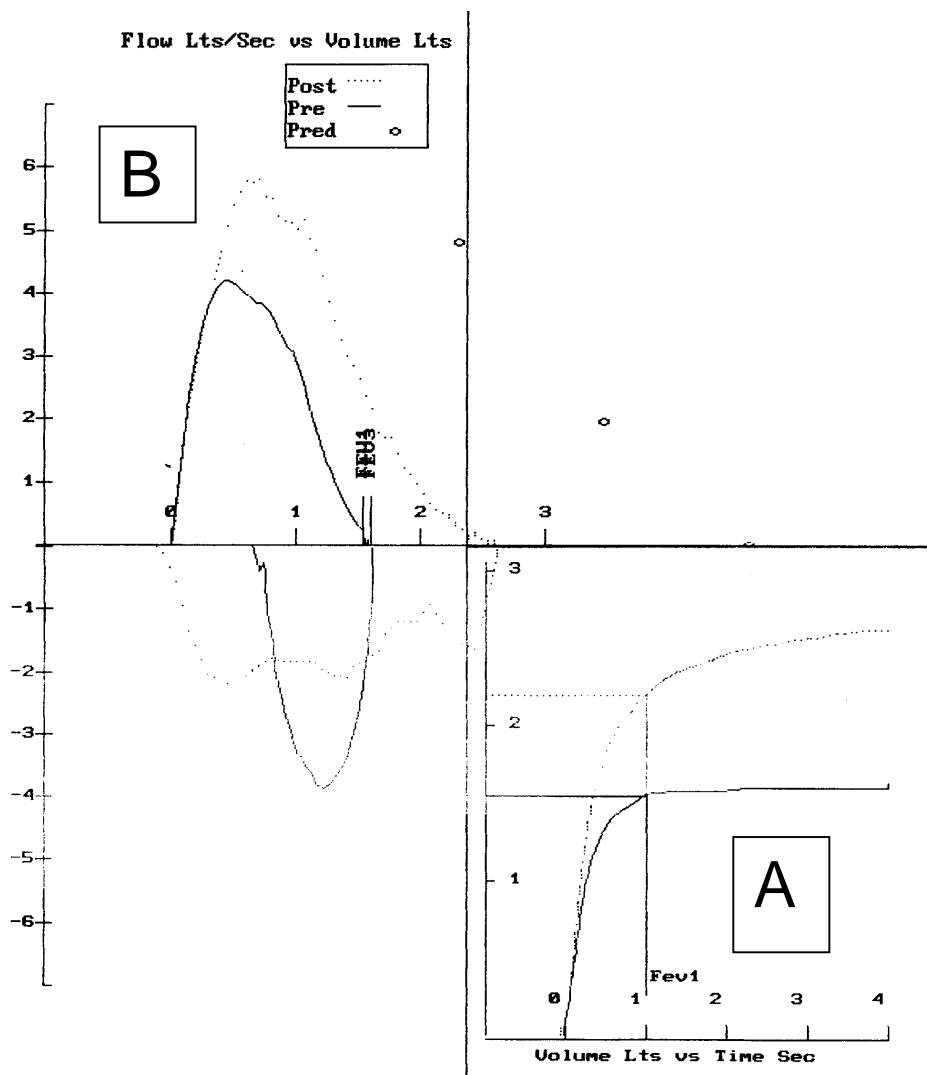


FIGURE 1: Spirometric Tracing

## DISCUSSION

The results of the present study suggest that electrical stimulation of the abdominal muscles can improve expiratory flows and volumes in some patients with SCI. The larger the disparity between achieved and predicted values for the expiratory flows and volumes during the volitional effort, the greater the gain in the measured PFT value when electrical stimulation was applied.

The feasibility of using abdominal muscle stimulation to improve cough in patients with SCI has been demonstrated in a number of studies.<sup>4,5,6,7</sup> Researchers employing surface electrodes in patients have reported that maximum expiratory pressure can be increased over volitional when either manually assisted cough or electrically assisted cough are used.<sup>4</sup> Investigators measuring PEFR during cough have reported similar improvements over volitional for manually assisted or electrically assisted cough.<sup>5</sup> The use of electromagnetic stimulation has also been studied with human subjects, showing increases in cough peak flow rate.<sup>6,7</sup>

In all of the human studies which involved the expiratory muscles previously discussed,<sup>4,5,6,7</sup> none have attempted to assess the state of the upper motor neuron paralyzed

muscles with respect to atrophy. It is likely that these muscles in most patients had undergone varying degrees of disuse atrophy. Thus, it is reasonable to assume that the immediate increases over volitional obtained with electrical stimulation in the present study are “worst case” values. These values might be improved as the abdominal muscles are more frequently activated by electrical stimulation, since chronic electrical stimulation of upper motor neuron paralyzed skeletal muscle has been shown to increase the strength of stimulated contractions, as well as improve fatigue resistance. Chronic stimulation in phrenic pacing has also been shown to strengthen the diaphragm, and improve fatigue resistance.<sup>8</sup>

In conclusion, the present study has indicated that electrical stimulation of abdominal muscles in patients with SCI can be used to improve performance during standard clinical PFT. The challenge of the future is to exploit the untapped potential of abdominal muscles in improving pulmonary function for patients with SCI on a daily basis. This could potentially lead to a reduction of pulmonary complications and an increased quality of life for patients with SCI.

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