

Electrical stimulation of human abdominal muscles

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Abstract

Abdominal muscles are the most important expiratory muscles in active expiration, such as during coughing. Spinal cord injured patients may suffer respiratory complications because of abdominal muscle paralysis and subsequent reduced ability to cough. In 6 able-bodied subjects, we compared twitch pressures from a single electrical pulse through surface electrodes, postero-laterally and anteriorly on the torso to twitches from magnetic stimulation of nerve roots at T10 level. A gastro-oesophageal catheter measured gastric pressure (P_{Ga}) and oesophageal pressure (P_{Oes}). Stimuli were delivered at increasing intensity (to 450 mA) at functional residual capacity (FRC) in the seated posture and at the maximal intensity at total lung capacity (TLC). Twitch pressures were greatest with electrical stimulation postero-laterally and magnetic stimulation at T10 and smallest at the anterior site (P_{Ga} 30±3 and 33±6 cmH₂O vs. 12±3 cmH₂O; P_{Oes} 8±2 and 11±3 cmH₂O vs. 5±1 cmH₂O; mean±SEM). At TLC twitch pressures were generally larger. The values were comparable to those evoked by magnetic stimulation. In 4 spinal cord injured patients 1-s trains of 50Hz stimulation were superimposed on voluntary cough efforts. Stimulation increased P_{Ga} by 217% and expiratory flow by 26% during cough efforts. The postero-lateral stimulation site was the optimal site for generating gastric and oesophageal twitch pressures compared to the anterior stimulation site. Abdominal muscle stimulation enhances the ability to cough in spinal cord injured patients.

1. INTRODUCTION

During normal breathing, expiration is usually passive. However, the activity of expiratory muscles becomes crucial during increased ventilation, cough or expulsive manoeuvres. The abdominal muscles are the most important expiratory muscles for active expiration.

Patients with spinal cord injury resulting in abdominal muscle paralysis have an increased risk of respiratory complications because of their reduced ability to cough [1]. Electrical or magnetic stimulation of the abdominal muscles has the potential to improve the ability of these patients to cough and help clear lung secretions [2, 3].

This study was designed to determine the optimal site and method for electrical stimulation of the abdominal muscles to generate abdominal and thoracic twitch pressures. In patients with spinal cord injury, we also assessed the ability of abdominal muscle stimulation to improve the effectiveness of their cough.

2. METHODS

2.1. Electrode position

In 6 healthy able-bodied subjects, the twitch pressures produced by a single electrical pulse (monophasic, 200 μ s width) through surface electrodes placed postero-laterally on the torso were compared to the twitch pressures produced by magnetic stimulation of the nerve roots at the level of T10 [e.g. 3] and electrical stimulation of the anterior surface of the torso as described in previous studies (Fig. 1) [e.g. 2].

Twitch pressures were recorded from a gastro oesophageal catheter with transducers in the stomach to record gastric pressure (P_{Ga}) and in the oesophagus to record oesophageal pressure (P_{Oes}). Twitch pressures were recorded at increasing stimulus intensities (50–450 mA) at functional residual capacity (FRC) in the seated posture and at the maximal intensity at total lung capacity (TLC; Fig. 1).

2.2. Stimulated cough

In 4 male patients with chronic spinal cord injury (level C3/C4, C4, C7/T1, T6), we recorded twitch pressures at increasing stimulus intensities at FRC, as described above. In addition, we recorded pressure and flow generated voluntarily during attempted coughs

(from TLC), during coughs with a superimposed 1-s, 50 Hz stimulus train, and with the stimulus train only. Maximal expiratory pressures with and without stimulation trains were also recorded. The stimulus current for the 1-s trains was set for each patient to produce a similar gastric pressure as during a voluntary cough (70-120 mA).

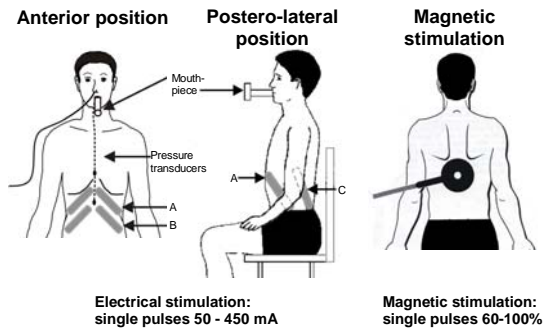


Figure 1. Schematic showing electrode placement positions for anterior, postero-lateral and magnetic stimulation.

3. RESULTS

3.1. Electrode position

In all cases, the highest twitch pressures were evoked by electrical stimulation postero-laterally and magnetic stimulation at T10 than at the anterior site (Table 1 and Figs. 2 and 3). At TLC twitch pressures were generally larger.

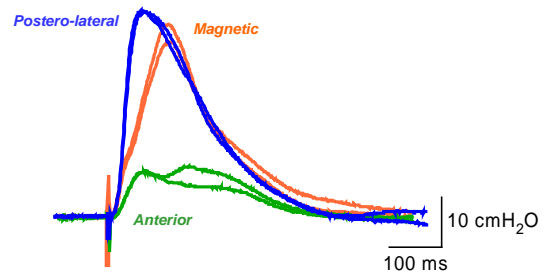


Figure 2. Representative twitch pressures (2 per site) from one subject (450mA at FRC). The pressures were similar for postero-lateral and magnetic stimulation, but were much smaller twitches for the anterior site.

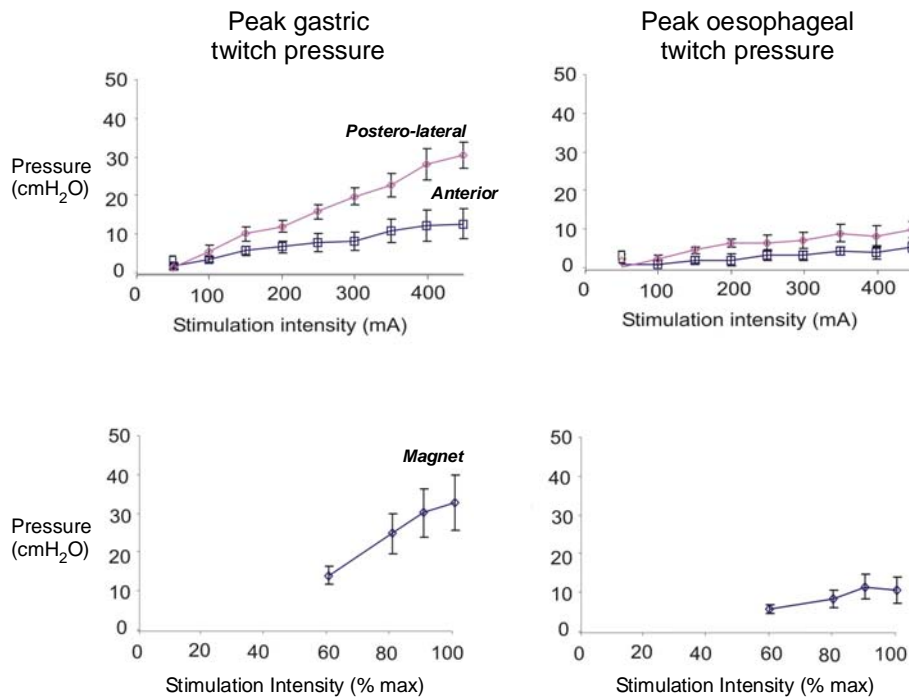


Figure 3. P_{Ga} and P_{Oes} twitch pressures plotted at each stimulation intensity. Note that P_{Ga} is much greater for stimulation at the postero-anterior position than the anterior position, but similar to the maximal magnetic stimulation.

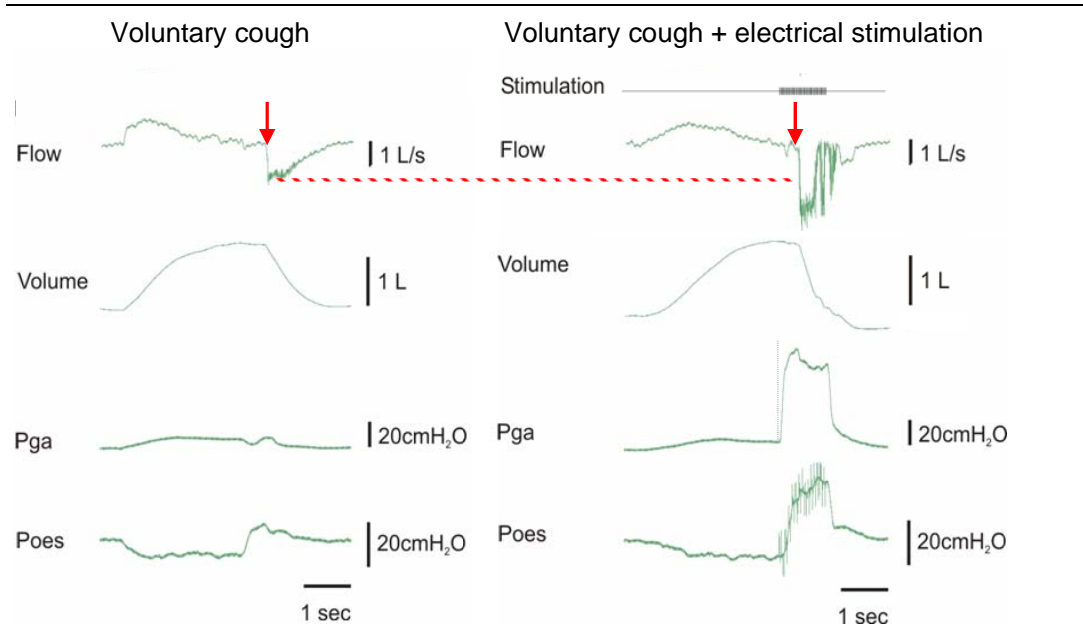


Figure 4. Raw traces from a spinal cord injured patient. Left: Voluntary cough showing little increase in gastric pressure. Right: Voluntary cough during abdominal electrical stimulation. Note the marked increase in abdominal pressure and the increase in flow and volume. The arrow marks the onset of the voluntary cough.

Table 1. Mean peak twitch pressures at maximal stimulus intensity (450 mA).

Stimulation site	P _{Ga} cmH ₂ O (mean ± SEM)	P _{Oes} cmH ₂ O (mean ± SEM)
Anterior	12 ± 3*	5 ± 1*
Postero-lateral	30 ± 3*	8 ± 2*
Magnet	33 ± 6*	11 ± 3*

comparable to those evoked by magnetic stimulation.

Twitch pressures at TLC were larger than at FRC.

From TLC expiratory flows were largest using the postero-lateral electrode site.

In spinal cord injured patients, voluntary cough pressure, flow and volume can be significantly augmented by abdominal electrical stimulation.

3.2. Stimulated cough

Maximal twitch pressures in the spinal cord injured patients ranged from 18 to 28 cm H₂O, similar to the able-bodied subjects. Peak P_{Ga} during maximal expiratory efforts was increased from 30 cmH₂O for voluntary efforts to 60 cmH₂O for voluntary efforts with superimposed stimulation trains. During cough efforts, peak P_{Ga} was increased by 217% with the added stimulation train (see Fig. 4). Peak flow rate during cough was increased by 26% with superimposed stimulation and exhaled volume during cough was increased by 87% (Fig. 4).

4. DISCUSSION AND CONCLUSIONS

The postero-lateral stimulation site was the optimal site for generating gastric and oesophageal twitch pressures compared to the anterior stimulation site. The values were

References

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Acknowledgements

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