ANALYSIS OF TRUNK MOTION DURING ELECTRICALLY 
STIMULATED COUGH IN SPINAL CORD INJURY

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Abstract
The feasibility of using electrical stimulation of 
abdominal muscles to produce or augment cough in 
spinal cord injury has been demonstrated. Past studies 
have focused exclusively on the measurement of airflow 
at the mouth or expiratory pressures during electrically 
stimulated cough. The present study examined the 
actual movements of the trunk during electrical 
stimulation of the abdominal muscles to augment cough, 
in order to better understand the underlying 
biomechanical effects of the stimulated muscle 
contractions. This could lead to discovering more 
optimal placement of electrodes and timing of stimulus 
delivery. While there are some similarities between 
subjects, there also appears to be some differences. 
These differences in underlying biomechanical 
movements may account for the variability between 
subjects seen in studies of cough production or 
augmentation.

Introduction/Background
The feasibility of using electrical stimulation of 
abdominal muscles to produce or augment cough and 
tidal volume during breathing in spinal cord injury has 
been demonstrated [1],[2]. Past studies have focused 
exclusively on the measurement of airflow at the mouth 
or pressures during electrically stimulated cough.

The present study examined the actual movements 
of the trunk during electrical stimulation of the 
abdominal muscles, in order to better understand the 
underlying biomechanical effects of the stimulated 
muscle contractions, which could lead to discovering 
more optimal placement of electrodes and timing of 
stimulus delivery.

In a previous study on the action of abdominal 
muscles on the rib cage in neurologically intact 
individuals, selective electrical stimulation of the rectus 
abdominus (RA) and external obliques (EO) showed 
different actions of these muscles, with RA tending to 
make the rib cage more elliptical along the antero-posterior (AP) diameter and decreasing the 
transverse diameter [3].

In an earlier study by Estenne and DeTroyer of 
votional cough in individuals with SCI, it was reported 
that the rib cage showed clear and consistent decrease in 
AP diameter of its upper portion, and after a sometimes 
transient increase in the AP diameter of the lower rib 
cage, also showed a decrease in AP diameter. In 
contrast, the abdomen showed an increase in AP 
diameter during cough [4].

Methods
Subjects: Three individuals with cervical spinal 
cord injury who could tolerate the stimulation were 
studied. All subjects provided informed consent and all 
experimental procedures were approved by the local 
Human Studies Committee. Subjects were studied 
seated in their personal wheelchairs.

Stimulators and Electrodes: Subjects were asked to 
produce as natural a cough as possible after a period of 
quiet breathing. A pair of EMPI Focus™ two channel 
nemuscular stimulators were used. Pulse width and 
frequency were constant at 250 us and 50 pps. 
Amplitudes were maximal (approx 100 mA). Two pairs 
of electrodes from the first stimulator were placed 
bilaterally over the RA muscles, and two pairs of 
electrodes from the second stimulator were placed 
bilaterally over the EO muscles. The stimulators were 
triggered by a computer with a 100 ms delay between 
the onset of the EO stimulation and RA stimulation.

Motion Analysis: A WATSMART system was used.
Six active infrared markers were placed on the trunk. 
Three markers were placed on the rib cage at the level of 
the nipples (approximately fourth intercostal space), one 
marker on the midline, the other two markers approximately six cm to the left and right. Three 
makers were placed on the abdomen just above the 
level of the umbilicus, again, one marker on the midline, 
and two markers approximately six cm to the left and 
right. Marker positions were plotted for each of the
three principal axes.

Since this was an exploratory descriptive study with a small number of subjects, no hypotheses were tested and no statistical tests were performed.

Results

The most striking result was a lack of uniformity across subjects. The behavior of the markers will be presented in each of the three principle directions, medio-lateral, antero-posterior (AP), and superior-inferior (vertical).

In one of the three subjects, the right and left lateral chest markers were seen to move medially during stimulation, indicating constriction of the chest, as shown in Fig. 1.

![Fig. 1](image)

Fig. 1: Unfiltered lateral movement of chest markers from a single trial. Right (R), center (C) and left (L) markers from top to bottom respectively. Note right and left markers move toward the midline during cough indicating contraction of the chest wall. In this trial, the subject produced two successive coughs.

The behavior of the abdominal markers in the lateral direction was less consistent across subjects. In two of the three subjects, the movements of the abdominal markers during cough were reasonably symmetrical on the left and right sides. In contrast, the other subject showed asymmetry between left and right sides.

The most significant movements in this study took place along the antero-posterior and vertical directions. In each of the figures below (Figs. 2-5 for subject 1 and Figs. 6-9 for subject 2) a single marker from a single trial of a volitional cough (light trace) and stimulated cough (heavy trace) are superimposed. The traces are raw, unfiltered marker movements from the WATSMART system. Calibration bars are provided for each figure, and differ between figures because of amplitude differences. The relative position of the two traces is aligned in time to place the beginning of the stimulation in the center of the plot, and in the vertical direction to facilitate amplitude comparisons between traces.

There are four plots for each subject, AP movement of chest, AP movement of abdomen, vertical movement of chest, and vertical movement of abdomen.

In subject 1, rather weak volitional coughs produced only small or in some traces, no deviations from tidal breathing. Stimulated coughs produced readily apparent movements in all traces. In subject 2, movements during volitional coughs were apparent in all traces, and stimulated coughs tended to produce similar movements that were greater in amplitude. Subject 3 was similar to subject 1, but with weaker coughs in both the volitional and stimulated conditions. Table 1 summarizes the effects of the stimulation on the movements produced in all three subjects. Related results from [4] are also included in the last line of the table for comparative purposes.

![Fig. 2](image)

Fig. 2: Subject 1 AP Chest. Positive trace (↑) is chest moving inwards.

![Fig. 3](image)

Fig. 3: Subject 1 AP abdomen. Positive trace (↑) is abdomen moving inwards.

![Fig. 4](image)

Fig. 4: Subject 1 vertical chest. Positive trace (↑) is chest moving up.

![Fig. 5](image)

Fig. 5: Subject 1 vertical abdomen. Positive trace (↑) is abdomen moving up.
Table 1: Summary of Stimulated Movements in AP and Vertical Directions

<table>
<thead>
<tr>
<th>SUBJ</th>
<th>Chest AP</th>
<th>Abd AP</th>
<th>Chest Vert</th>
<th>Abd Vert</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (C5 inc)</td>
<td>out</td>
<td>in</td>
<td>up</td>
<td>down</td>
</tr>
<tr>
<td>2 (C4 comp)</td>
<td>in</td>
<td>out</td>
<td>down</td>
<td>down</td>
</tr>
<tr>
<td>3 (C3 comp)</td>
<td>out</td>
<td>in</td>
<td>up</td>
<td>down</td>
</tr>
<tr>
<td>ref [4]</td>
<td>in</td>
<td>out</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Discussion/Conclusions

Our results indicate that while electrical stimulation of abdominal muscles can produce enhanced cough, much more careful study is needed on the independent and concurrent roles of RA and EO in cough, the potential difference in the timing of stimulation to these muscle groups, and the relative symmetry of resulting muscle contractions. While all subjects showed an increase in cough when stimulated, it is clear that the movements of the trunk are not uniform across subjects.

Our results are not in complete agreement with those of Estenne and DeTroyer [4]. These authors also reported some variability in their data (e.g. subjects 5 and 6 in their Fig. 1). Our marker placement was likely comparable to their lower rib cage and abdominal traces. Our protocol for subject producing cough also differed from theirs in that they asked subjects to pause briefly against a closed glottis, whereas we instructed subjects to cough in a manner that was normal for them.

Additional subjects are being studied to enable a statistical analysis. Current work is focused on exploring the contributions of RA and EO alone and in concert.

References


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