

## Expiratory muscle activity and nasal expiratory pressure during reverse sniff

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**Objective:** We examined whether the maximal nasal pressure during a short and sharp expiration, a reverse sniff (R-sniff) akin to "blowing your nose quickly," is useful for assessing expiratory muscle strength through direct measurement of electromyogram (EMG) activity.

**Methods:** Maximal R-sniff nasal expiratory pressure (RSNEP<sub>max</sub>) and maximal expiratory mouth pressure (MEP<sub>max</sub>) were measured from functional residual capacity (FRC) in 19 healthy participants. Then, in another 9 healthy participants, we inserted fine wire electrodes into the transversus abdominis muscle (TA), and measured RSNEP and TA EMG activity during the 20–40 R-sniffs of various intensity including RSNEP<sub>max</sub> and MEP<sub>max</sub> maneuvers from FRC.

**Results:** RSNEP<sub>max</sub> and MEP<sub>max</sub> correlated significantly ( $r = 0.06$ ,  $P = 0.007$ ). TA EMG activity appeared in every participant, even at lower RSNEP levels. RSNEP and TA EMG activity correlated significantly ( $r = 0.772–0.922$ ,  $P < 0.001$ , respectively). There was no significant difference between TA EMG activity during RSNEP<sub>max</sub> and MEP<sub>max</sub> maneuvers.

**Conclusion:** These findings suggest that TA, a main expiratory muscle, contributes to a generation of RSNEP<sub>max</sub>. We conclude that RSNEP<sub>max</sub> accurately reflects expiratory muscle activity and is useful as a simple and noninvasive assessment that complements MEP<sub>max</sub> in a comprehensive evaluation of expiratory muscle strength.

**Key words:** expiratory muscle strength, reverse sniff, transversus abdominis muscle, respiratory muscle electromyogram, nasal expiratory pressure

### Introduction

In patients with respiratory disease and neuromuscular disease, the major causes of morbidity and mortality are airway and respiratory complications, such as aspiration and pneumonia.<sup>1-3</sup> These complications are partly protected by the cough mechanism, which clears airway secretions.<sup>4,5</sup> The sequence of events that leads to an effective cough has been classified into an inspiratory phase when a volume of air is inhaled into the lungs, a compressive phase involving forced expiration against a closed glottis, and an expiratory phase when the glottis opens to allow rapid expiratory flow out of the airway.<sup>4,6</sup> Expiratory muscle strength is a significant determinant of peak expiratory flow during a cough, particularly in

neuromuscular disease.<sup>7,8</sup> Therefore, accurate expiratory muscle strength evaluation is necessary to prevent respiratory complications.

The maximal expiratory mouth pressure (MEP<sub>max</sub>) maneuver has achieved wide acceptance as the noninvasive assessment of choice for expiratory muscle strength.<sup>9-12</sup> However, some patients lack the ability and motivation to perform MEP<sub>max</sub> because of the level of load required.<sup>13</sup> Furthermore, patients with neuromuscular disease involving orofacial muscle weakness may have difficulty forming an airtight seal around the mouthpiece, leading to MEP<sub>max</sub> underestimation.<sup>14</sup> It has been recognized that not only inspiratory but expiratory muscles were important for respiration and cough,<sup>15-17</sup> and the gastric pressure during

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a maximal voluntary cough (cough  $P_{ga}$ ) has been presented as an alternative technique of measuring expiratory muscle strength due to the use of abdominal expiratory muscles in cough.<sup>9,18</sup> However, this technique might be not able to be used readily in clinical settings because measuring cough  $P_{ga}$  requires the invasiveness of inserting a balloon catheter into the stomach. Although peak cough flow (PCF) is also a well-known technique used for cough efficacy assessment including expiratory muscle strength, it has been reported that PCF was determined not only by expiratory but also by inspiratory muscle strength.<sup>19</sup>

Although maximal inspiratory mouth pressure ( $MIP_{max}$ ) is traditionally used to assess inspiratory muscle strength, nasal inspiratory pressure measured during a maximal sniff is gaining acceptance as a novel method of assessing inspiratory muscle strength.<sup>9,13,20,21</sup> This maneuver benefits from the ability to evaluate inspiratory muscle strength in patients with orofacial muscle weakness because it is performed through a nostril. Moreover, research has suggested that the maximal sniff nasal inspiratory pressure was better suited than  $MIP_{max}$  for assessing the progression of inspiratory muscle weakness in patients with amyotrophic lateral sclerosis.<sup>21</sup>

Based on the positive results from the development of the sniff maneuver, we hypothesized that measuring pressure during a maximal, short, sharp expiration through a nostril, referred to as the "reverse sniff" (R-sniff; akin to blowing your nose quickly), might offer a simple and noninvasive assessment of expiratory muscle strength. To apply maximal R-sniff clinically, we must examine whether the nasal expiratory pressure recorded by it is indicative of expiratory muscle strength. To our knowledge, to date, there are no references regarding the R-sniff nasal expiratory pressure (RSNEP) by searching the PubMed database for articles written between 1946 and September 2014. Therefore, in the present study, we aimed to confirm the usefulness of the maximal RSNEP ( $RSNEP_{max}$ ) for the assessment of expiratory muscle strength through direct measurement of electromyogram (EMG) activity.

## Materials and Methods

A total of 28 male participants were recruited by open recruitment for the present study. They all provided written informed consent to participate in the study which was approved by the Kitasato University Medical Ethics Organization (KMEO B02-04).

### *Measurements for the relationship between $RSNEP_{max}$ and $MEP_{max}$*

$RSNEP_{max}$  and  $MEP_{max}$  were measured using Vitalpower (KH-101; Chest MI, Tokyo) in 19 healthy male participants (age: 20–26 years, height: 163–180 cm, weight: 45–80 kg) without any history of respiratory or neuromuscular disorders. Both measurements were repeated at functional residual capacity (FRC) more than 3 times until the deviation between the 3 largest values was within 20%, and the maximal values were analysed, respectively.  $RSNEP_{max}$  was measured with the peak pressure during a maximal R-sniff through a cone-shaped attachment that occluded one nostril, while the contralateral nostril remained open. Before the measurements were taken, the participants learned FRC adequately with visual feedback of the respiratory flow on a monitor. Moreover, they practiced a maximal R-sniff repeatedly, described as "blowing your nose quickly" to achieve a maximal, short, sharp, forced expiration through the nostril. After their practice,  $RSNEP_{max}$  was measured in a sitting position. We selected a maximal R-sniff of <500 ms in duration and a pressure tracing showing a sharp peak for analysis according to the criteria of the suitable sniff.<sup>22</sup>  $MEP_{max}$  was also measured with the 1-second average pressure in a sitting position with a mouthpiece, according to the established practice.<sup>9</sup>

### *Expiratory muscle activity during R-sniff and $MEP_{max}$ maneuvers*

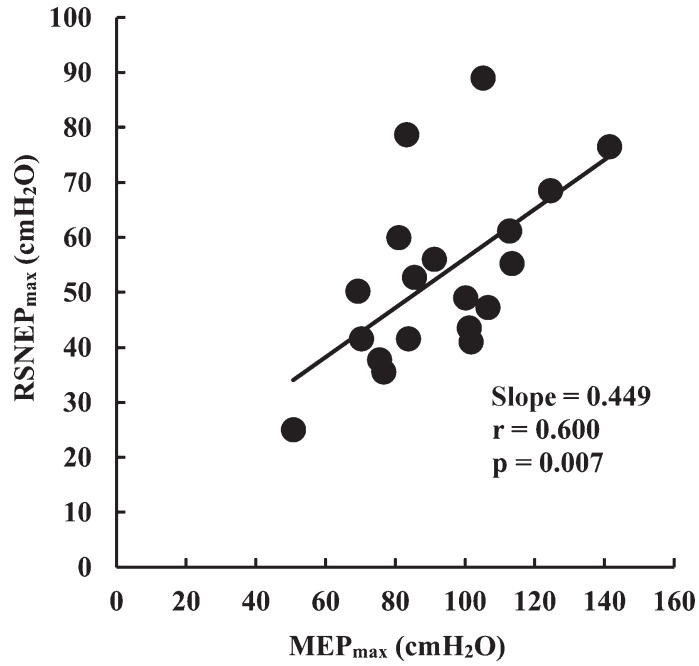
Nine other healthy male participants (age: 20–33 years, height: 164–178 cm, weight: 56–82 kg) without any history of respiratory or neuromuscular disorders were studied during the expiratory muscle activity during R-sniff and  $MEP_{max}$  maneuvers.

### *Electrode measurement*

Details of the fine wire EMG techniques used in this study are published elsewhere.<sup>15,16,23,24</sup> A pair of fine wire electrodes was inserted, approximately 10 mm apart, into the transversus abdominis muscle (TA) 1 cm below the right costal margin on the anterior axillary line under high-resolution ultrasound guidance.

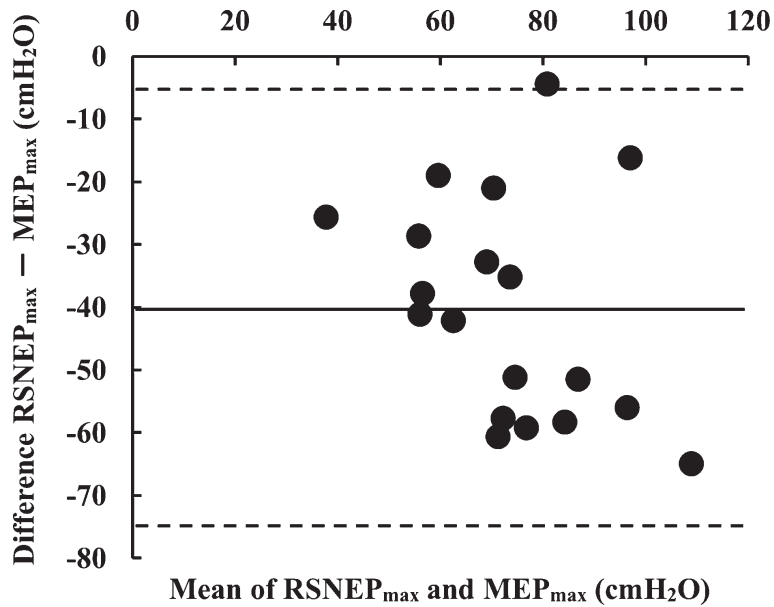
The raw EMG signals from the electrodes were band-pass filtered (50 Hz to 4 kHz), rectified and processed by a resistance capacity with a time constant of 50 milliseconds to provide continuous moving average (Mavg) EMG data for TA. Maximal EMG ( $EMG_{max}$ ) of TA was defined as the greatest Mavg EMG activity recorded during various respiratory and non-respiratory maneuvers for each participant. Maximal activity of TA was elicited by the Valsalva maneuver, forced expiration

Reverse sniff nasal expiratory pressure



**Figure 1.** Relationship between RSNEP<sub>max</sub> and MEP<sub>max</sub>

Maximal expiratory mouth pressure (MEP<sub>max</sub>) and maximal reverse sniff nasal expiratory pressure (RSNEP<sub>max</sub>) are shown on the X and Y axes, respectively. RSNEP<sub>max</sub> showed a significant positive correlation with MEP<sub>max</sub> (r = 0.600, P = 0.007).



**Figure 2.** A Bland-Altman plot of the differences between RSNEP<sub>max</sub> and MEP<sub>max</sub> against the mean of RSNEP<sub>max</sub> and MEP<sub>max</sub>

The bias, represented by the mean of the difference between maximal reverse sniff nasal expiratory pressure (RSNEP<sub>max</sub>) and maximal expiratory mouth pressure (MEP<sub>max</sub>), was -40.2 cmH<sub>2</sub>O (continuous line). The limits of agreement, bias ± 2 standard deviations, were -74.6 to -5.8 cmH<sub>2</sub>O (dotted lines).

from total lung volume to residual volume (RV), and vital capacity maneuver from FRC to RV, along with the maximal R-sniff and MEP<sub>max</sub> maneuvers. The peak Mavg EMG activity of TA during the R-sniff and MEP<sub>max</sub> maneuvers was expressed as %EMG<sub>max</sub>.<sup>23</sup> EMG<sub>max</sub> values during the respiratory and nonrespiratory maneuvers were assessed before and after this study to confirm EMG electrodes.

*Measurements of RSNEP and MEP<sub>max</sub>*

The nasal catheter and the mouthpiece were attached to a pressure transducer (DX312, Omeda, Singapore) for measurements of RSNEP and MEP<sub>max</sub>, respectively. Before measurements, they learned FRC adequately with a visual feedback of the respiratory flow on the monitor, then they practiced the R-sniff and MEP<sub>max</sub> maneuvers at FRC several times. Using the visual feedback of RSNEP or MEP<sub>max</sub> on the monitor, the participants were asked to perform the 20–40 R-sniffs of various intensity from low to high including maximal intensity and the MEP<sub>max</sub> maneuver from FRC. Recordings were performed while the participants were sitting because this is how they are typically measured in clinical settings. We selected short (<500 milliseconds) and sharp R-sniffs for analysis.<sup>22</sup>

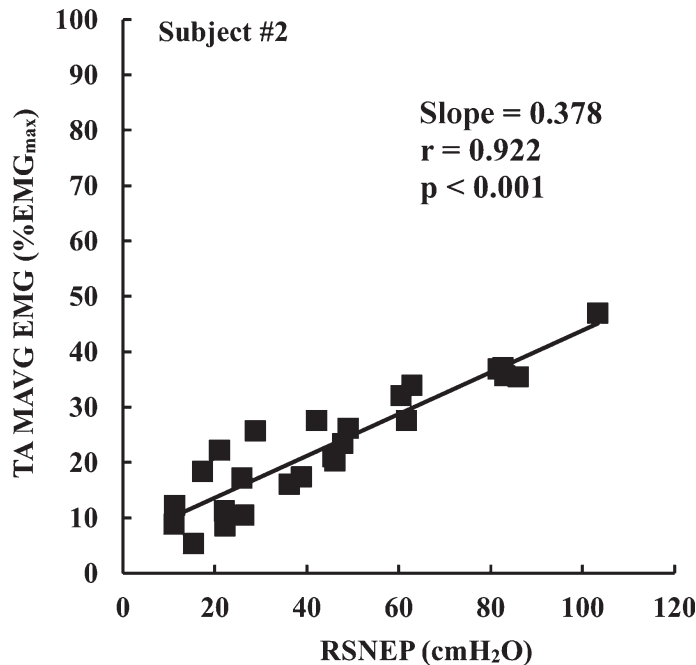
RSNEP and MEP<sub>max</sub> were analysed as the peak pressure and the 1 second average pressure, respectively. All pressure signals were then merged with EMG data on the hard disk on a microcomputer at 4 kHz using the PowerLab 16/30 system and Labchart 7 software (ML880; AD Instruments, Bella Vista, Australia).

*Statistical analyses*

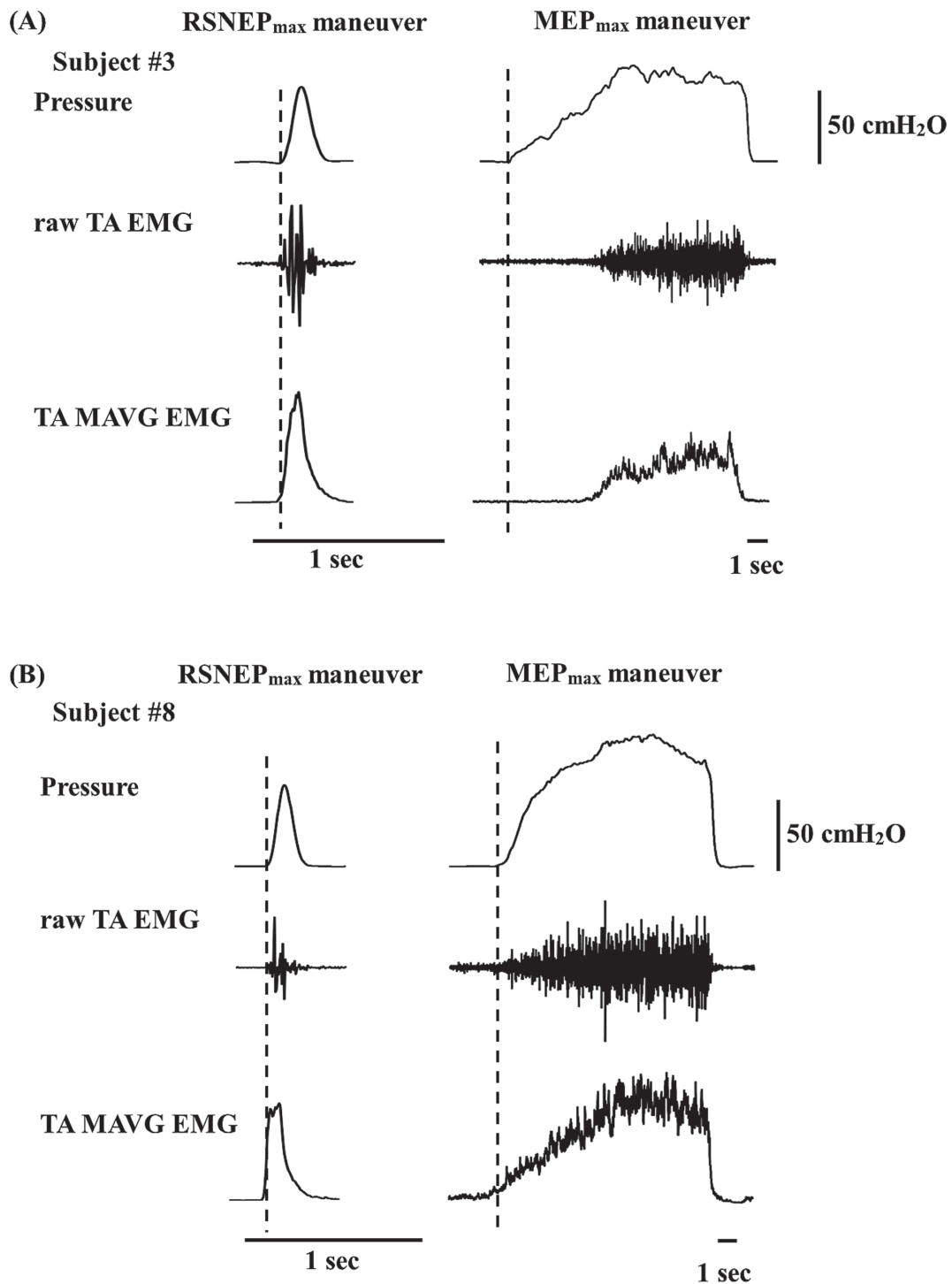
Values were exported for review to spreadsheet software (Microsoft Excel, Microsoft, Redmond, WA, USA) to output Figures 1–4. Statistical analyses were executed by the personal computer version of IBM SPSS Statistics version 20 (IBM SPSS, NY, USA).

The relationship between RSNEP<sub>max</sub> and MEP<sub>max</sub> was calculated by linear regression using the least squares method. The agreement between RSNEP<sub>max</sub> and MEP<sub>max</sub> was assessed by the methods of differences against the means described by Bland and Altman.<sup>5,25</sup>

Differences in values between RSNEP<sub>max</sub> and MEP<sub>max</sub> and in TA EMG activity between RSNEP<sub>max</sub> and MEP<sub>max</sub> were compared using the Wilcoxon signed-rank test. Moreover, the relationship between the EMG response in TA and RSNEP was assessed by linear regression for each participant. P < 0.05 was considered significant.



**Figure 3.** Relationship between RSNEP and TA Mavg EMG activity  
Reverse sniff nasal expiratory pressure (RSNEP) is shown on the X axis; the moving average (Mavg) electromyogram (EMG) activity of the transversus abdominis muscle (TA) showed a significant linear relationship with increasing RSNEP.



**Figure 4.** The onset of TA EMG activity during RSNEP<sub>max</sub> and MEP<sub>max</sub> maneuvers

Pressure, moving average (Mavg) electromyogram (EMG) and raw EMG data for the transversus abdominis muscle (TA) are shown in top, middle and bottom traces, respectively. Moreover, these traces during maximal reverse sniff nasal expiratory pressure (RSNEP<sub>max</sub>) and maximal expiratory mouth pressure (MEP<sub>max</sub>) maneuvers are shown on the right and left sides, respectively. (A) The onset of TA EMG activity during RSNEP<sub>max</sub> maneuver was simultaneous with that of pressure generation but was delayed during MEP<sub>max</sub> maneuver. (B) The onset of TA EMG activity during both RSNEP<sub>max</sub> and MEP<sub>max</sub> maneuvers were simultaneous with those of pressure generation.

## Results

### *Relationship between RSNEP<sub>max</sub> and MEP<sub>max</sub>*

Mean RSNEP<sub>max</sub> and MEP<sub>max</sub> were  $53.2 \pm 16.3$  [mean  $\pm$  standard deviation (SD)] centimeters of water (cmH<sub>2</sub>O) and  $93.4 \pm 21.7$  cmH<sub>2</sub>O, respectively ( $P < 0.001$ ). The 95% confidence intervals of the mean were 46.1–60.3 cmH<sub>2</sub>O for RSNEP<sub>max</sub> and 83.9–102.9 cmH<sub>2</sub>O for MEP<sub>max</sub>. A significant positive linear relationship was observed between RSNEP<sub>max</sub> and MEP<sub>max</sub> ( $r = 0.600$ ,  $P = 0.007$ , Figure 1). The bias between RSNEP<sub>max</sub> and MEP<sub>max</sub> was  $-40.2$  cmH<sub>2</sub>O, with RSNEP<sub>max</sub> lower than MEP<sub>max</sub>, and the limits of agreement ranged from  $-74.6$  to  $-5.8$  cmH<sub>2</sub>O using a Bland-Altman plot (Figure 2).

### *TA activity during R-sniff and MEP<sub>max</sub> maneuvers*

Discomfort was minimal during fine wire electrode insertion, respiratory and nonrespiratory maneuvers, and R-sniffs and MEP<sub>max</sub> measurements; no participant required analgesia. Recorded EMG<sub>max</sub> values during the respiratory and nonrespiratory maneuvers were not significantly different before and after this study in any participant.

### *RSNEP and raw EMG data for TA*

Even at the lower RSNEP (approximately 10 cmH<sub>2</sub>O),

raw EMG data suggested TA activity, which increased with each stepwise increment in RSNEP in all 9 participants. The progression of EMG activity with RSNEP for TA is illustrated for a typical participant in Figure 5.

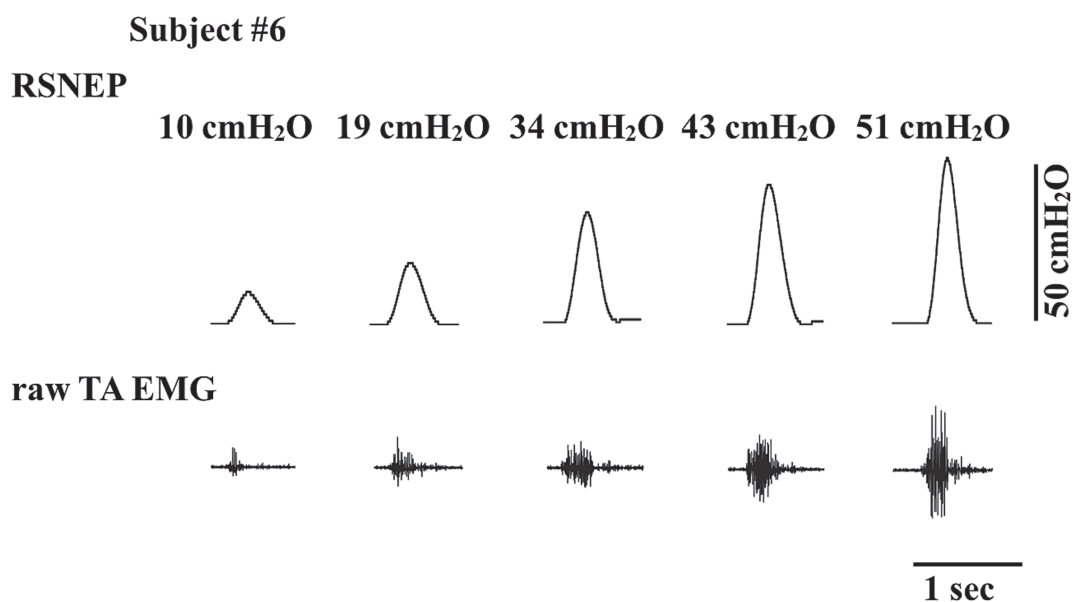
### *Relationship between stepwise RSNEP increases and TA Mavg EMG*

The relationship between increasing RSNEP and TA activity, expressed as %EMG<sub>max</sub>, is illustrated in Figure 4. Typically, TA EMG activity increased linearly with increasing RSNEP ( $r = 0.922$ ,  $P < 0.001$ ). These significant positive correlations were observed in all 9 participants, providing a mean coefficient of correlation and slope ( $\Delta\%EMG_{max}/\Delta RSNEP$ ) of  $0.871 \pm 0.055$  ( $P < 0.001$ ) and  $0.832 \pm 0.406$ , respectively (Table 1).

### *Differences between TA EMG activity and pressure during RSNEP<sub>max</sub> and MEP<sub>max</sub> maneuvers*

Mean RSNEP<sub>max</sub> and MEP<sub>max</sub> were  $72.5 \pm 23.6$  cmH<sub>2</sub>O and  $100.5 \pm 24.4$  cmH<sub>2</sub>O, respectively ( $P = 0.008$ ). Conversely, the mean TA EMG activity during the RSNEP<sub>max</sub> and MEP<sub>max</sub> maneuvers were  $57.2 \pm 22.6$  %EMG<sub>max</sub> and  $52.6 \pm 30.4$  %EMG<sub>max</sub>, respectively. No significant difference was observed between those TA EMG activities.

The onset of TA EMG activity during the RSNEP<sub>max</sub>



**Figure 5.** RSNEP and raw TA EMG

Reverse sniff nasal expiratory pressure (RSNEP) is shown in the upper trace. Raw electromyogram (EMG) activity of the transversus abdominis muscle (TA) is shown in the lower trace. The first to fifth RSNEP values were approximately 10, 20, 30, 40, and 50 cmH<sub>2</sub>O. The duration of each reverse sniff was  $<500$  ms. Raw EMG data for TA was detectable at the lower RSNEP values and increased with stepwise increments in RSNEP.

**Table 1.** Relationship between RSNEP and TA Mavg EMG activity

Subject	Slope (%EMG <sub>max</sub> /RSNEP)	r	P
1	1.204	0.906	<0.001
2	0.378	0.922	<0.001
3	1.157	0.878	<0.001
4	1.510	0.923	<0.001
5	0.795	0.772	<0.001
6	0.961	0.884	<0.001
7	0.319	0.841	<0.001
8	0.627	0.802	<0.001
9	0.537	0.914	<0.001

RSNEP, reverse sniff nasal expiratory pressure; TA, transversus abdominis; Mavg EMG, moving average electromyogram; EMG<sub>max</sub>, maximal Mavg EMG activity per muscle. Mavg EMG activity was expressed as %EMG<sub>max</sub>.

maneuver was always simultaneous with that of pressure generation in all participants. However, the onset of TA EMG activity was always delayed during the MEP<sub>max</sub> maneuver in 4 participants and was simultaneous in 5 participants. The onset of both TA EMG activity and pressure changes are illustrated for typical participants in Figure 4.

## Discussion

### *RSNEP<sub>max</sub> as an indicator of expiratory muscle strength*

One aim of this study was to examine whether RSNEP<sub>max</sub> was a valid indicator of expiratory muscle strength. RSNEP<sub>max</sub> was the pressure obtained during a maximal, short, sharp expiration through a nostril. According to the previous study,<sup>5</sup> the expiratory mouth pressure, measured during comparable expiration through a narrow aperture (i.e., whistle mouth pressure), was closely related to the esophageal and gastric pressures both in patients with amyotrophic lateral sclerosis and in healthy participants. Moreover, because whistle mouth pressure and MEP<sub>max</sub> correlated with wide limits of agreement in healthy participants, those investigators suggested that this represented a complementary evaluation of expiratory muscle strength.<sup>5</sup> Our maximal R-sniff through a nostril is comparable to the mouth whistle maneuver, as each requires a maximal, short, sharp, dynamic expiration.

In the present study, RSNEP<sub>max</sub> and MEP<sub>max</sub> were measured from FRC rather than total lung volume, because the expiratory pressure at FRC has been the pure total sum of the collective activity of expiratory

muscles.<sup>9,26</sup> If the expiratory pressure is measured at the lung above FRC, expiratory muscle strength is overestimated due to the passive elastic recoil pressure of respiratory system including the lung and chest wall. Actually, maximal sniff nasal inspiratory pressure was measured from FRC to estimate the pure inspiratory muscle strength.<sup>22</sup> From our investigation, RSNEP<sub>max</sub> had a linear relation to MEP<sub>max</sub>, as did whistle mouth pressure in the previous report.<sup>5</sup> Moreover, during various intensity R-sniffs, TA EMG activity was observed at all RSNEP levels in all participants, increasing in a stepwise manner with increasing RSNEP levels. Because TA is known to be the most active of the 4 abdominal muscles during expiration,<sup>15</sup> TA was probably the crucial expiratory muscle for producing RSNEP.

RSNEP<sub>max</sub> and MEP<sub>max</sub> demonstrated positive linear regression in the present study. However, the limits of agreement between RSNEP<sub>max</sub> and MEP<sub>max</sub> were wide, and RSNEP<sub>max</sub> showed statistically lower values than MEP<sub>max</sub>. Several factors could be responsible for these results. First, consistent with the sniff maneuver, R-sniff was achieved through an occluded nostril with the contralateral nostril remaining clear to allow the passage of air.<sup>9</sup> However, MEP<sub>max</sub> was measured against a nearly complete occlusion. Moreover, the maximal R-sniff was only briefly measured through a nostril within 500 ms, while MEP<sub>max</sub> generated sustained pressure with maximal effort through the mouth for longer than 1.5 seconds. These differences between dynamic and sustained static methods may have caused different recruitment and coordination of expiratory muscle groups. In other words, the total activation of expiratory muscle groups during the RSNEP<sub>max</sub> maneuver might be less compared with that during the MEP<sub>max</sub> maneuver. Consequently, these findings indicated that RSNEP<sub>max</sub> was a valid, but complementary, technique for assessing expiratory muscle strength.

### *TA EMG activity during RSNEP<sub>max</sub> and MEP<sub>max</sub> maneuvers*

In the present study, the onset of TA EMG activity was simultaneous with that of pressure generation during the RSNEP<sub>max</sub> maneuver in all participants. In contrast, the onset of TA EMG activity was delayed in 4 of 9 participants during MEP<sub>max</sub> maneuver. These findings suggested that some expiratory muscles other than TA might be additionally activated during MEP<sub>max</sub> maneuvers, possibly because it is performed against a near-complete occlusion and requires a sustained maximal effort.

During a cough, which is a dynamic and brief

maneuver as the RSNEP<sub>max</sub> maneuver, the abdominal expiratory muscles (the TA, the internal and external oblique, and rectus abdominal muscles) were simultaneously and vigorously activated in anesthetized cats<sup>27</sup> and healthy human participants.<sup>17,28</sup> Thus, the 4 abdominal expiratory muscles might activate simultaneously with the RSNEP<sub>max</sub> generation. On the other hand, previous studies have reported that the onset timing of the activation of these abdominal expiratory muscles were different from each other during expiratory threshold loading breathing in anesthetized cats<sup>27</sup> and sustained voluntary efforts (i.e., expiration from FRC and expulsive maneuvers) in healthy human participants.<sup>17</sup> From these studies, it was possible that the activation patterns of abdominal expiratory muscles during the MEP<sub>max</sub> maneuver were different individually.

#### *Clinical implications*

A weakness of expiratory muscle strength predisposes patients with neuromuscular disease to cough impairment and pulmonary complications.<sup>4,7,8</sup> Expiratory muscle strength also supports increased physical activity in patients with chronic obstructive pulmonary disease (COPD).<sup>10</sup> Therefore, evaluating expiratory muscle strength is clinically important.

Although the MEP<sub>max</sub> maneuver is well established as a measure of expiratory muscle strength, it is limited by patient understanding, motivation, and coordination.<sup>9</sup> Furthermore, both MEP<sub>max</sub> and whistle mouth pressure cannot be accurately measured in patients with orofacial muscle weakness or bulbar dysfunction because of difficulties holding the mouthpiece. PCF, which is able to be easily measured through a tightly fitting mask even in those patients, is of clinical relevance for cough efficacy assessment. PCF has been also reported to strongly correlate with MEP<sub>max</sub> and cough P<sub>ga</sub> in patients with neuromuscular diseases.<sup>19</sup> However, cough is composed of inspiratory, compressive, and expiratory phases.<sup>4,6</sup> Actually, PCF has been affected by MIP<sub>max</sub> and maximal inspiratory capacity in neuromuscular patients.<sup>19,29</sup> Therefore, it is difficult to assess the pure expiratory muscle strength in measuring only PCF. However, RSNEP<sub>max</sub> from FRC maneuvers are technically easy to assess the true expiratory muscle strength and can be performed by most participants, even in these scenarios. As with the whistle mouth pressure, detailed instruction on how to perform the test is unnecessary, and R-sniff requires minimal practice allowing poorly motivated participants to produce maximal efforts immediately. Therefore, the RSNEP<sub>max</sub> maneuver is an easily used, complementary assessment of expiratory muscle strength.

In patients with bulbar disease, there might be some difficulties performing R-sniff because of upper airway collapse or inability to close the mouth completely, similarly to the sniff maneuver.<sup>30</sup> This is especially the case in the supine position, when it is necessary to stiffen the upper airway because of gravity. However, very little is known of the effect of different postures on both the expiratory and upper airway muscles and the consequent pressure during a maximal R-sniff. Moreover, the extent to which RSNEP<sub>max</sub> values demonstrate clinical expiratory muscle weakness have not also been investigated to date. Also, whether RSNEP<sub>max</sub> could be useful for assessing expiratory muscle strength in patients with orofacial disorders and COPD patients with respiratory muscle insufficiency has not been examined. Further research is needed to clarify these questions and establish the clinical relevance of the RSNEP<sub>max</sub> maneuver.

The present study indicated that RSNEP<sub>max</sub> accurately reflected expiratory muscle activity. The limits of agreement between RSNEP<sub>max</sub> and MEP<sub>max</sub> were wide, with RSNEP<sub>max</sub> lower than MEP<sub>max</sub>. Therefore, the nasal expiratory pressure during RSNEP<sub>max</sub> maneuvers may be a useful clinical indicator that complements MEP<sub>max</sub> in a comprehensive evaluation of expiratory muscle strength.

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