

Surface electromyography of accessory inspiratory muscle activity during upper airway obstruction

Masahiko Kanazumi¹, Yasuhiko Kato², Yasushi Sakuma² and Junichiro Kotani²

¹Graduate School of Dentistry (Department of Anesthesiology) and ²Department of Anesthesiology, Osaka Dental University, 8-1 Kuzuhahanazono-cho, Hirakata-shi, Osaka 573-1121, Japan

In a previous study, we examined how changes in breathing pattern affect the electromyographic (EMG) activity of accessory inspiratory muscles during spontaneous breathing. The present study aimed to create a device that simulates progressive upper airway obstruction to examine how such obstruction relates to EMG changes and respiratory movement. The subjects were 8 men and women between 26 and 47 years of age with normal cardiopulmonary function. A two-in-one airway pressure and flow monitor mask and a pulse oximeter were secured to the subjects, and electrodes were placed bilaterally on the sternocleidomastoid muscles. A heat and moisture exchange filter was attached to the tip of the airway pressure and flow monitor, and 1 mL/min of 2% methylcellulose solution was injected into the filter using a syringe pump. As airway resistance gradually increased over time, changes in accessory inspiratory muscle activity, airway pressure, expiratory flow, and percutaneous oxygen saturation were measured. Following spike count processing, changes in the spike count were calculated at one-minute intervals. Spike counts for the intervals between 5 and 6 minutes and 6 and 7 minutes were significantly greater than for the other intervals. Whereas the average airway pressure among all subjects increased over time, and increased significantly starting from the interval between 4 and 5 minutes, expiratory flow significantly decreased starting from this same interval. SpO₂ started to decrease from the interval between 5 and 6 minutes and was significantly lower over the next interval. These findings indicate that the sternocleidomastoid muscle may be actively recruited as an accessory inspiratory muscle during inspiratory movement associated with increased airway resistance. Furthermore, given the significant EMG changes observed before SpO₂ decreased, electromyography may be a more sensitive monitoring method of upper airway obstruction than pulse oximetry. (J Osaka Dent Univ 2015 ; 49(1) : 129–135)

Key words : Surface electromyography ; Sternocleidomastoid muscle ; Inspiratory muscle ; Upper airway obstruction

INTRODUCTION

Although numerous electromyographic (EMG) studies of muscle activity have been performed, few have examined in detail the relationship between respiratory state and respiratory muscle activity. This is primarily because the muscles involved in respiration are situated deep in the body, making EMG assessment extremely difficult due to high noise levels. In a previous study, we examined how changes in breath-

ing pattern affect EMG activity of the accessory inspiratory muscles in the neck during spontaneous breathing.¹ The results indicated that the relationship between respiratory state and accessory inspiratory muscle activity could be quantitatively analyzed using spike count-processed surface electromyograms. The objective of the present study was to create a device that simulates progressive upper airway obstruction to examine how such obstruction relates to EMG changes and respiratory movement.

MATERIALS AND METHODS

Subjects

Eight men and women aged between 26 and 47 years of age with normal cardiopulmonary function participated in this study. After the purpose of the study was fully explained, subjects provided informed consent to participate. The study was approved by the Ethics Committee of Osaka Dental University (No.110728).

Experimental device

The experimental device developed was composed of two units, one for taking measurements and another for simulating airway obstruction. A disposable face mask (Value Mask King Systems, Noblesville, IN, USA) was tightly secured to the subject's head with a rubber band, an integrated airway pressure and flow monitor (Ohmeda 5250 RGM; GE Healthcare Japan, Tokyo, Japan) was attached to the breathing hole of the mask, and a heat and moisture exchange filter (Humid-Vent Small S; Intermed Japan, Osaka,

Japan) was connected to the end of the monitor. This system allowed us to measure and record airway pressure and expiratory flow (Fig. 1).

In addition, following the experimental methods of Sakuma *et al.*,² we dissolved methylcellulose #1500 (Nacalai Tesque, Kyoto, Japan) in distilled water to create a 2% solution. This solution was injected through the tracheal tube connected to the injection port on the heat and moisture exchange unit of the breathing circuit to spread the solution over the filter (Fig. 2). During the experiment, injection of a fixed volume of the solution caused the area for ventilation to decrease gradually, thereby increasing respiratory resistance and simulating upper airway obstruction.

Measurement system

The Bagnoli-2 EMG system, a surface electromyograph that has high signal resolution and verified

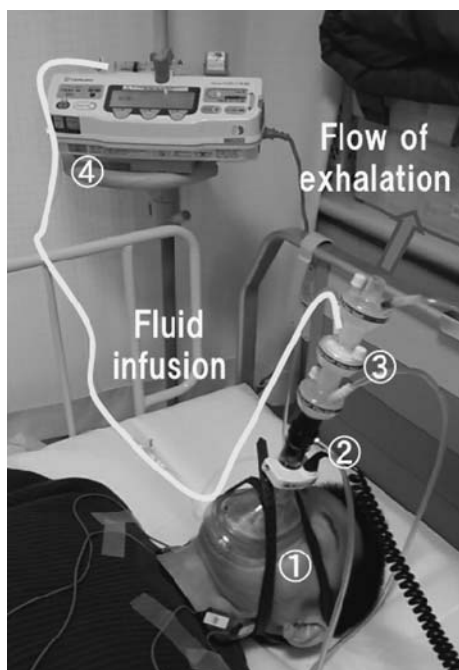


Fig. 1 Measurement apparatus. A disposable face mask ① was secured tightly to the subject's nose and mouth, an airway pressure and flow monitor ② was attached to the mask, and a heat and moisture exchange filter ③ was connected to the end of the monitor. Solution was injected into the heat and moisture exchange filter at 1 mL/min using a syringe pump ④.



Fig. 2 Injection apparatus. A 2% methylcellulose solution injected through the injection port spreads across the surface of the paper filter inside the heat and moisture exchange filter.

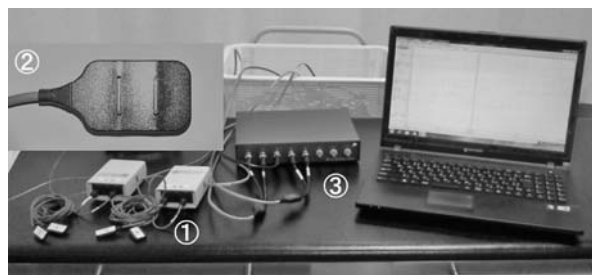


Fig. 3 The Bagnoli-2 EMG system components comprised of a Bagnoli-2 Main Amplifier Unit ①, surface electrodes (DE-2.1 EMG Sensors) ② and an analog-digital converter (UAS-A 3) ③. In addition to EMG data, data input from the airway pressure and flow monitor and the pulse oximeter were sent to the analog-to-digital converter and recorded in real time with a personal computer.

noise reduction capabilities, comprises a main Bagnoli-2 Main Amplifier Unit (Delsys, Boston, MA, USA) surface electrodes (DE-2.1 EMG Sensor ; Delsys) ; and an analog-digital converter (UAS-A 3 ; Unique Medical, Tokyo, Japan) (Fig. 3).

Electromyographic recording

Given the findings of our previous basic research,¹ we decided to monitor the sternocleidomastoid muscle because, unlike other accessory inspiratory muscles, its EMG activity can be recorded with surface electrodes. Four surface electrodes were placed bilaterally over the upper and lower sides of the muscle at the bifurcation into the clavicular and sternal branches, and EMG activity was recorded using a bipolar wire with an inter-electrode distance of 10 mm (Fig. 4). As each EMG unit can record measurements via two channels, muscle activity in both sides of the sternocleidomastoid muscle was measured via four channels. These data were sent to an analog-to-digital converter and recorded in real time on a personal computer. The sites for the electrodes were wiped with sanitary cotton moistened with alcohol, conductive gel was applied to the surface of the electrodes, and the electrodes were secured in alignment with muscle fibers using special tape.

Respiratory movement

After the experimental device was secured in place, the subject performed quiet breathing at rest in the su-



Fig. 4 Recording apparatus. The sensors were comprised of four surface electrodes placed bilaterally over the upper and lower sides of the sternocleidomastoid muscle at the bifurcation into the clavicular and sternal branches, and a bipolar wire with an inter-electrode distance of 10 mm to record EMG activity.

pine position. Airway pressure and expiratory flow were measured continuously while EMG activity was recorded. After 1 min, the 2% methylcellulose solution was injected into the heat and moisture exchange filter at a rate of 1 mL/min using a syringe pump (TE-352 ; Terumo, Tokyo, Japan) to successively increase respiratory resistance. The subject performed quiet breathing at rest during this period and was instructed to perform forced breathing as necessary if they experienced greater difficulty with breathing. During recordings, care was taken to limit head and neck movements to those being measured. The experiment was stopped when either 7 mL of solution had been injected or the subject indicated that it would be difficult to continue with the experiment, as reported previously.² In addition, a pulse oximeter (Biox 3740 Pulse Oximeter ; GE Healthcare Japan) was attached to the subject's fingertip and arterial oxygen saturation (SpO₂) was recorded. The values displayed during the experiment were moving averages over periods of 3 second duration.

Data acquisition and analysis

The obtained EMG activity and other data were computed using the UAS-308 S data collection system. Although EMGs were recorded bilaterally across the sternocleidomastoid muscle, the waveform with the least baseline fluctuation and clearest muscle activity was selected for analysis. Because there was no significant increase in muscle activity and no changes in airway pressure or expiratory flow for 30 s post-injection, electric potential was measured every 6 seconds for a total of 5 measurement points. The values were averaged to produce a threshold level for each noise component.

The period from starting the injection to conclusion of the experiment was divided into a total of seven one-minute intervals, and the number of signals above the threshold level (spike count) was tabulated for each interval (Table 1). The spike count for the one-minute period post-injection was used as a control, and percent change from that value was calculated for each interval to determine relative changes in muscle activity over time (Fig. 5). Airway pressure and expiratory flow were calculated from the obtained

Table 1 Number of signals above the threshold level in each of the seven one-minute intervals during the experiment

Age, Sex Electrode location	0-1	1-2	2-3	3-4	4-5	5-6	6-7
34, male ③	1116.5	811.5	791.0	764.0	1715.5	3957.0	3702.5
47, male ④	1854.0	1837.5	1802.0	1952.5	3819.5	3896.0	3858.5
31, female ①	2557.0	2463.5	2266.0	2366.0	2669.5	3392.5	3230.0
32, female ②	2410.0	2563.5	2542.5	2573.0	3389.0	3458.5	3503.5
30, male ①	1645.0	1579.0	1619.0	1550.0	1773.0	2444.0	2437.5
27, male ②	1221.5	1406.0	1406.5	1473.0	2212.0	1981.5	1387.0
26, female ②	737.5	755.0	736.5	746.5	1349.0	1367.5	1735.5
30, male ④	669.0	708.5	498.0	408.5	632.0	1728.0	2773.5
Mean	1526.3	1515.6	1457.7	1479.2	2194.9	2778.1	2828.5
SD	715.4	740.8	742.9	793.4	1059.4	1022.5	915.7

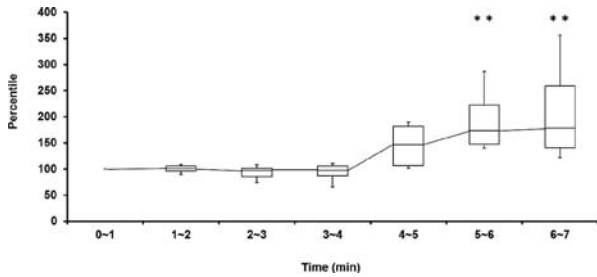


Fig. 5 Change in spike count for each of six subsequent one-minute intervals relative to the spike count for the one-minute period after injection used as a control (** $p < 0.01$ by Dunnett's test).

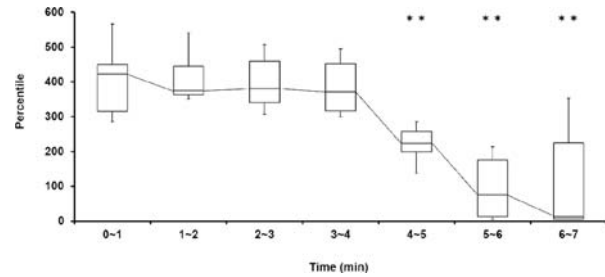


Fig. 7 Change in integrated expiratory flow over each one-minute interval.

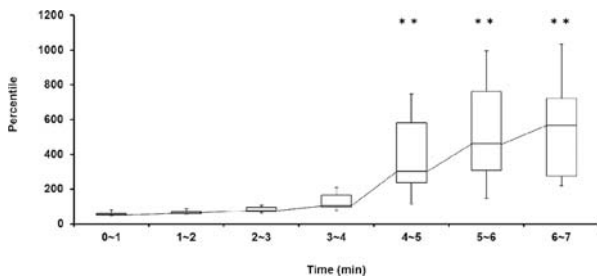


Fig. 6 Change in integrated airway pressure over each one-minute interval.

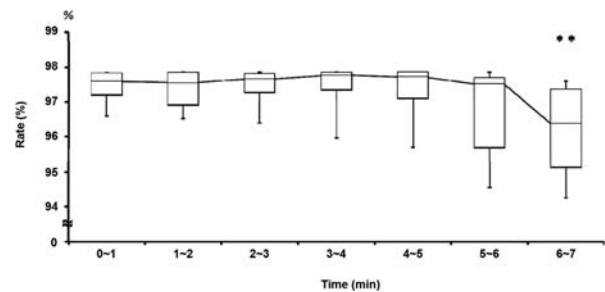


Fig. 8 Change in average SpO₂ measured over each one-minute interval.

waveforms as integrated values over each one-minute interval (Figs. 6 and 7). SpO₂ was taken as the average value measured during each one-minute in-

terval (Fig. 8).

Statistical analysis

Multiple comparison was used for statistical analysis with the significance level set at 0.05.

RESULTS

Figure 9 of representative EMG waveforms show EMG activity at the upper and lower regions of the left and right sides of the sternocleidomastoid muscle, as well as airway pressure, expiratory flow, and oxygen saturation. Although it appeared that muscle activity may have been increasing with respiratory exertion, it is difficult to distinguish this activity from the baseline noise that always exists on electromyograms. Compared with these electromyograms however, muscle activity was clearer on spike count-processed EMG waveforms (Fig. 10). The spike counts of the intervals

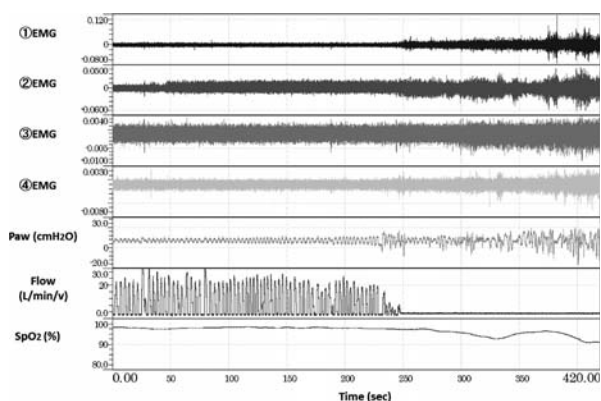


Fig. 9 Data. The waveforms numbered 1 to 4 show EMG activity in the sternocleidomastoid muscle, at the four recording sites shown in Fig. 4. The lower three graphs show the airway pressure, expiratory flow, and oxygen saturation, respectively.

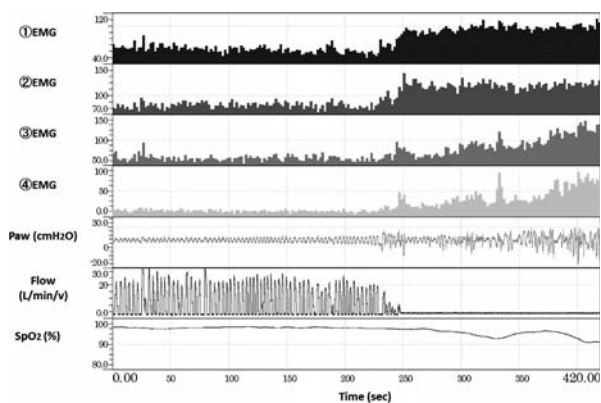


Fig. 10 Spike count-processed EMG waveforms. Baseline noise has been removed, making muscle activity clearer.

between minutes 5 and 6 and between minutes 6 and 7 were significantly greater than those of the control. This is probably because the sternocleidomastoid muscle became highly active after the rapid increase in airway pressure and the increase in respiratory resistance that occurred after injection of about 4 mL of solution.

Average airway pressure increased with time and increased significantly starting from the interval between minutes 4 and 5. Expiratory flow was unchanged before the interval between 3 and 4 minutes, and decreased significantly starting from the interval between 4 and 5 minutes. However, due to inconsistencies such as an increase in average flow from the interval between 5 and 6 minutes to the interval between 6 and 7 minutes, there was no completely consistent trend over time. SpO₂ decreased starting from the interval between 5 and 6 minutes and was significantly lower for the subsequent final interval.

DISCUSSION

Monitoring of sternocleidomastoid muscle activity

We used the sternocleidomastoid muscle to measure EMG activity of the accessory inspiratory muscles in this study. By definition, the accessory inspiratory muscles are a group of muscles that do not participate in respiration during rest, but are recruited during forced breathing.³ According to Campbell *et al.*, the accessory inspiratory muscles comprise the scalene, sternocleidomastoid, trapezius, as well as the pectoralis major and pectoralis minor muscles. Among these, the scalene and sternocleidomastoid muscles play a particularly important role.⁴ Although the sternocleidomastoid muscle behaves more like an accessory muscle than the scalene muscle, it is characterized by its intense participation as an inspiratory muscle under high inspiratory pressure.^{5,6}

Accessory inspiratory muscles are actively recruited as inspiratory muscles at times of increased ventilation due to tachypnea or an increase in lung volume, when there is increased airway resistance, and when there is respiratory muscle paralysis due to cervical spine injury.⁶ In this study, to simulate increased airway resistance, we simulated progressive

upper airway obstruction and recorded measurements as the patients passively performed forced breathing. Furthermore, we selected the sternocleidomastoid muscle as an indicator of upper airway obstruction because its EMG can be recorded noninvasively and easily with surface electrodes, and because it is actively recruited at times of increased airway resistance.

As the sternocleidomastoid muscle can change the position of the head,⁷ we kept the subjects in the supine position during measurements and were careful to minimize head and neck movement. However, we cannot rule out that such movement could have influenced the spike count-processed data if it created noise above the threshold level incorporated in the signal.

Simulating upper airway obstruction

To create a circuit that artificially simulates upper airway obstruction, we referred to the methods of Sakuma *et al.*² They reported that the viscosity of the fluid used to obstruct ventilation does not influence results because increased resistance in the circuit is achieved when the paper filter inside the heat and moisture exchange filter becomes soaked.² However, we used a viscous solution of methylcellulose #1500 in our circuit to prevent the liquid that passed through the filter from leaking and affecting the device. If we had used a ventilator, we would have injected a maximum of 7 mL of solution in human subjects to avoid raising airway pressure excessively, because the pressure in the circuit would rise to 40 cm H₂O if 8 mL of solution were injected.

Implications of the significant findings

At the interval between 5 and 6 minutes when about 4 mL of solution had been injected into the heat and moisture exchange filter, there was a decrease in expiratory flow accompanied by an opposing rapid increase in airway pressure synchronous with expiration, as well as elevated activity of the sternocleidomastoid muscle synchronous with inspiration. This is presumably because the volume of the area inside the heat and moisture exchange filter that was partitioned with the paper filter was about 4 mL. As a result, sig-

nificant changes in airway pressure and expiratory flow were seen after the volume reached that point. The reason why a significant change in spike count was not observed until the interval between 6 and 7 minutes, slightly later than changes in airway pressure and expiratory flow, was presumably that strong forced breathing became inevitably necessary once a larger volume of solution was injected and air flow was completely obstructed.

SpO₂ did not change at all until the interval between minutes 4 and 5, and started to decrease from the next interval between 5 and 6 minutes, to become significantly lower at the subsequent final interval. This change in SpO₂ was observed at a later point than changes in other measurement parameters. Although SpO₂ is the most common indicator of respiration used in clinical practice, it is known that the response time varies by measurement site.⁹ When SpO₂ is measured at the hand or finger as in the present study, there is a delay of 5 to 37 seconds.¹⁰ In addition, another study reports that the mean transit time from the pulmonary artery to radial artery is around 19 seconds, when subjects are resting.¹¹ These delays are probably reflected in our finding that changes in SpO₂ occur later than EMG changes.

We were able to clearly detect an increase in respiratory resistance from upper airway obstruction on spike count-processed electromyograms of the sternocleidomastoid muscle. This finding indicates that the sternocleidomastoid muscle may be actively recruited as an accessory inspiratory muscle during inspiratory movement associated with increased airway resistance. We also observed significant EMG changes before SpO₂ decreased. This important finding suggests that electromyography could be a more sensitive monitoring method of upper airway obstruction than pulse oximetry.

REFERENCES

1. Kanazumi M, Kato Y, Kotani J. Analysis of respiratory state and accessory inspiratory muscle activity by spike count processing of surface electromyogram. *J Osaka Dent Univ* 2014; **48**: 49–53.
2. Sakuma Y, Kato Y, Ando K, Kotani J. Sputum viscosity does not affect flow resistance in a heat and moisture exchange filter. *J Osaka Dent Univ* 2011; **45**: 233–235.
3. Da Troyer A, Loring SH. Action of the respiratory muscles. In :

- Macklem PT, Mead J, eds. Handbook of Physiology : The respiratory system. Section 3. Bethesda : Am Physiol Soc, 1986 ; **3** : 443–461.
4. Campbell EJM. The role of scalene and sternomastoid muscles in breathing normal subjects. An electromyographic study. *J Anat* 1955 ; **89** : 378–386.
 5. Ward ME, Eidelman D, Stubbing DG, Bellmare F, Macklem PT. Respiratory sensation and pattern of respiratory muscle activation during diaphragm fatigue. *J Appl Physiol* 1988 ; **65** : 2181–2189.
 6. Yokoba M, Abe T, Katagiri M, Dobashi Y, Yamada T, Tomita T. Electromyographic activity of neck muscles during the production of inspiratory pressure. *Nihon Kokyuki Gakkai Zasshi* 1999 ; **37** : 102–107. (Japanese)
 7. Goss CM, Gray H, Asami I, Shimai K, Kimura K, Setoguchi T, Deura S. Anatomy of the human body. 29th ed. Tokyo : Hironaka, 1981 ; **1** : 426–427. (Japanese)
 8. Sakuma Y, Kato Y, Ando K, Kotani J. Effects of heat and moisture exchanger type on changes in airway pressure due to sputum. *Shika Igaku (J Osaka Odontol Soc)* 2012 ; **75** : 18–21. (Japanese)
 9. Hamber EA, Bailey PL, James SW, Wells DT, Lu JK, Pace NL. Delays in the detection of hypoxemia due to site of pulse oximetry probe placement. *J Clin Anesth* 1999 ; **11** : 113–118.
 10. Eberhard P, Gisiger PA, Gardaz JP, Spahn DR. Combining transcutaneous blood gas measurement and pulse oximetry. *Anesth Analog* 2002 ; **94** : 76–80.
 11. Lindholm P, Blogg SL, Gennser M. Pulse oximetry to detect hypoxemia during apnea : comparison of finger and ear probes. *Aviat Space Environ Med* 2007 ; **78** : 770–773.