An Alternative Approach to the Monitoring of Respiration by Dynamic Air-Pressure Sensor

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Monitoring and assessing of patient respiratory function during conscious sedation are important because many drugs used for conscious sedation produce respiratory depression and subsequent hypoventilation. The purpose of this study is to assess the value of a dynamic air-pressure sensor for respiratory monitoring of clothed patients. Eight clothed adult volunteers were reclined on a dental chair positioned horizontally. The air bag for measuring air-pressure signals corresponding to respiration was placed on the seat back of the dental chair in the central lumbar area of the subject. The subject breathed through a face mask with a respirometer attached for measuring expiratory tidal volume. The air-pressure signals corresponding to respiration were obtained and the time integration values for air pressure during each expiration ($\int P_{\text{exp}}$) were calculated. The expiratory tidal volume (TV_{exp}) was measured simultaneously by respirometer. The relationship between TV_{exp} and $\int P_{\text{exp}}$ for each subject was assessed by a Pearson correlation coefficient. A strong correlation between TV_{exp} and $\int P_{\text{exp}}$ was observed in all subjects. Measuring $\int P_{\text{exp}}$ by dynamic air-pressure sensor makes it possible to estimate respiratory volume breath by breath, and the respiratory pressure–time integral waveform was useful in visually monitoring the respiration pattern. We believe that in the future this device will be used to monitor respiratory physiology in clothed patients, contributing to safer sedative procedures.

Key Words: Air-pressure sensor; Respiratory; Monitor; Nonrestrictively.

Conscious sedation is a pharmacologically induced state of relaxation in which the patient remains conscious and cooperative throughout dental treatment.¹ However, monitoring and assessing patient respiratory function during conscious sedation are important because many drugs used for conscious sedation produce respiratory depression and subsequent hypoventilation.

At present, the noninvasive methods utilized for continuous quantitative monitoring of breathing patterns include respiratory inductive plethysmography, tidal volume (TV) measured by pneumotachograph, and end-tidal carbon dioxide monitoring using a capnograph.^{2–4} Respiratory inductive plethysmography has become an eminent standard for unobtrusive respiratory monitoring and has been used widely in clinical and research settings, but patients experience some discomfort wearing the necessary 2 bands, multiple wires, and tapes on their skin.⁵ The measurement of TV requires a device such as a spirometer or pneumotachometer connected to the patient via mouthpiece and nose clip or face mask. This equipment is uncomfortable, and in some patients produces a sensation of smothering.⁶ End-tidal

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Demographic Data*

Variable	Mean $\pm$ SD	Range
Age (y)	32 $\pm$ 6	26-44
Weight (kg)	59 $\pm$ 10	47-73
Height (cm)	166 $\pm$ 9	153-179
Body mass index (kg/m ²)	21.4 $\pm$ 2.37	18.1-25.3

* n = 8 subjects (3 women, 5 men).

carbon dioxide monitoring is inaccurate when patients breathe through the mouth, so the sampling line is inserted through a nasal cannula or attached to a nasal mask during dental procedures. In light of these disadvantages, a new method for noninvasive monitoring of patient's breathing is needed. Responding to this need, a dynamic air-pressure sensor system has been invented that measures respiration and heart movements without the use of a harness or sensor on the subject's body. The new technique is already being used to research sleep apnea syndrome.⁷

The purpose of this study was to assess whether there is a correlation between the dynamic air-pressure sensor to monitor respiratory activity in clothed patients and the expiratory volume measured by a respirometer in order to consider whether this device might be useful for monitoring patient's respiratory function during conscious sedation.

METHODS

Subjects

Eight adult volunteers (3 women and 5 men) were picked randomly from the Hiroshima University staff; volunteers had not been taking any regular medication and were free of respiratory disease or other significant medical problems (Table 1).

Measurement by Dynamic Air-Pressure Sensor

A dynamic air-pressure sensor (Body Movement Sensor BMS 21; Advance, Tokyo, Japan) was used to convert body weight shifts from respiratory movements to pressure fluctuations. It consisted of a dynamic air pressure generator composed of an air bag enclosing a sponge to obtain an air layer 25 $\times$ 25 $\times$ 4 (width $\times$ depth $\times$ height) mm. It included a dynamic air pressure detector comprising a piezoelectric device and a dynamic pressure transmission path composed of polyvinyl chloride tubing. It had an output sensitivity of 1 mV/kPa in the frequency range of 0.1 Hz to 1 kHz (Figure 1).

The air bag was placed on the back seat of the dental chair positioned under the central lumbar area of the subject. The obtained analog air-pressure signals showing the total activity of the body were amplified and transmitted to a personal computer at a sampling rate of 1 kHz through a converter. The signal corresponding

Figure 1. Dynamic air-pressure sensor system.

Figure 2. A typical record of respiratory air-pressure waveform obtained from dynamic air-pressure sensor (top) and integral waveform (bottom).

to respiration (the respiratory air-pressure signal) was extracted from the combined signals in the frequency range of 0.15–0.47 Hz. Furthermore, the respiratory air-pressure signal was integrated to yield volume (Chart software, AD Instruments, Bella Vista, Australia).

Measurement by Respirometer

The measurement of expiration volume by respirometer was carried out simultaneously for comparison with the respiration information measured by the dynamic air-pressure sensor. Subjects breathed through a tight-fitting face mask attached to a respirometer (Wright respirometer, Ferraris Respiratory, Hertford, UK), and the device was videotaped for analysis of expiratory TV (TV_{exp}).

Procedure

Subjects wore cotton 2-piece clothing and reclined on a standard dental chair positioned horizontally. The air bag of the dynamic air-pressure sensor and the mask with attached respirometer were set in place. After confirming at least 5 minutes of natural breathing, subjects were instructed to breathe in a continuous pattern of 3 types of breathing; 2 deep breaths, approximately 10 natural breaths, and 5 breaths that gradually became deeper.

Data Analysis

Sequential respiratory data were obtained from 2 deep breaths, approximately 10 natural breaths, and 4 breaths gradually becoming deeper. A fifth breath after the final 4 was excluded because, in the subjects' enthusiasm to make the final deepest breath, excessive body

movements created an unreliable noisy signal that could not be analyzed. The respiratory air-pressure signal was integrated and the time integration values of respiratory air pressure for each expiration ($\int P_{exp}$) were calculated. The TV_{exp} for each expiration was measured by the respirometer. The relationship between TV_{exp} and $\int P_{exp}$ for each subject was assessed by a Pearson correlation coefficient.

Statistical Analysis

Statistical analysis was performed using Stat View 5.0 (SAS Institute Inc, Cary, NC, USA) for Windows. Statistical differences were considered significant when $P < .05$.

RESULTS

Demographic data are shown in Table 1. In 8 volunteers, the respiratory air-pressure signal and the expiratory tidal volume were recorded and analyzed for each subject. Figure 2 shows a typical record of respiratory air-pressure waveform and integral waveform. Figure 3 shows the relationship between TV_{exp} and $\int P_{exp}$ for each subject. Pearson correlation coefficients ranged from 0.888 to 0.983. A strong correlation between TV_{exp} and $\int P_{exp}$ was observed for all subjects.

DISCUSSION

In the present study we compared the $\int P_{exp}$ extracted from respiratory movement by dynamic air-pressure sensor to TV_{exp} for each expiration in each subject. We

Figure 3. The relationship between TV_{exp} (the expiratory tidal volume) and $\int P_{exp}$ (the time integration values of pressure fluctuations extracted from respiratory movement by dynamic air-pressure sensor) for each subject. A strong correlation between TV_{exp} and $\int P_{exp}$ was observed for all subjects.

found a strong correlation between $\int P_{exp}$ and TV_{exp} . The results showed that the dynamic air-pressure sensor was useful in monitoring the respiratory status of the clothed patient noninvasively and nonrestrictively.

The dynamic air-pressure sensor was developed to record respiratory effort noninvasively. This device is characterized by the fact that its sensor pad is set in place without being directly attached to the body. Because this sensor pad is reusable, this system has cost-saving benefits. In this study, the air bag was placed under the central lumbar area of the clothed subject to monitor pressure fluctuations caused by abdominal contractions

during respiration. During inspiration, as the thorax/abdomen expands, the pressure sensor receives positive pressure and the respiratory air-pressure signal waveform shows positive deflection. Conversely, during expiration, the waveform shows negative deflection. In the respiratory pressure–time integral waveform, the rising part of the wave represents an inspiration phase and the descending part represents an expiration phase.

We calculated the Pearson correlation coefficient to test for significant correlations between $\int P_{exp}$ and TV_{exp} . The result was a strong linear correlation in all subjects. The data showed that $\int P_{exp}$ measured by the dynamic

air-pressure sensor allowed accurate estimation of respiratory volume breath by breath.

Individual differences were observed in the $\int P_{\text{exp}}$ value for the same TV_{exp} value. Tidal volume can be partitioned into a component caused by the rib cage muscle contraction and a component caused by diaphragmatic contraction.⁸ Respiratory inductive plethysmography estimates the amount of air moved by the respiratory system by measuring the expansion and contraction of both the rib cage and abdominal compartments.⁹ In this study, because a single sensor was placed in the lumbar area, it may be picking up only abdominal movement, which may have caused the individual differences in $\int P_{\text{exp}}$. Furthermore, if the subject is obstructed, the abdomen will still move and provide false data that the subject is exchanging air. It may be possible to measure respiratory volume more accurately and to perceive asynchrony and paradoxical motion of the rib cage and abdominal compartments using 2 dynamic air sensors placed behind the rib cage and abdomen.

Another weakness of this device is that the respiratory air-pressure data is influenced by sudden pressure fluctuations like a strong body movement, although it is not influenced by static pressure difference in body weight.

Another major finding was that a respiratory pressure-time integral waveform was useful in visually monitoring the breathing pattern. The rising part of the integral waveform represents the expiration phase and the descending part represents the inspiration phase. An observer can easily perceive a change in the breathing pattern, breath by breath.

CONCLUSION

There was a strong correlation between TV_{exp} and $\int P_{\text{exp}}$ for all subjects. Our results demonstrate that the respi-

ratory pressure-time integral waveform obtained by dynamic air-pressure sensor was useful to visually monitoring respiration. We believe that in the future this device will be used to monitor respiratory physiology in clothed patients, contributing to safer sedative procedure.

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