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Thoracic ROM Measurement System with Visual Bio-feedback: System Design and Biofeedback Evaluation

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Abstract— Patients with diseases such as chronic obstructive pulmonary disease (COPD) need to improve their thorax mobility. Thoracic ROM is one of the simplest and most useful indexes to evaluate the respiratory function. In this paper, we have proposed the prototype of a simple thoracic ROM measurement system with real-time visual bio-feedback in the chest expansion test. In this system, the thoracic ROM is measured using a wire-type linear encoder whose wire is wrapped around the thorax. In this paper, firstly, the repeatability and reliability of measured thoracic ROM was confirmed as a first report of the developed prototype. Secondly, we analyzed the effect of the bio-feedback system on the respiratory function. The result of the experiment showed that it was easier to maintain a large and stable thoracic ROM during deep breathing by using the real-time visual biofeedback system of the thoracic ROM.

I. Introduction

THE ability to accurately diagnose and evaluate respiratory function is critical and useful in such disorders as chronic obstructive pulmonary disease (COPD), ankylosing spondylitis, asthma, and thoracic scoliosis, where respiratory dysfunction can be dangerous and even fatal [1-5]. Some kinds of pulmonary rehabilitation programs or certain medications can affect respiration, and monitoring these effects can be useful to the clinical researcher [6]. In addition, the respiratory function needs to be checked before and after the surgery.

Thoracic Range of Motion (ROM), which is defined as the difference between chest circumference in maximal exhalation and that in maximal inhalation, is one of the most important and simplest indexes to evaluate the respiratory function. Thoracic ROM therapy is done to improve thoracic mobility and flexibility, because decrease in thoracic ROM increases oxygen consumption and leads to exacerbation of fatigue and shortness of breath. In clinical rehabilitation, the thoracic ROM is manually measured by a tape measure in the chest expansion test [7]. This method is very simple for the physical therapist. However, it is difficult for the patients to understand their own respiratory condition and to sustain motivation for rehabilitation.

Some researchers developed the chest circumference measurement device. Tawa et al used optical sensor and acceleration sensor [8]. Merritt et al developed a textile-based sensor for respiration monitoring [9]. The evaluation of measurement systems has been done well. However, the effect of biofeedback on respiration has not been evaluated.

The purpose of this paper is to propose and develop an automatic thoracic ROM measurement system without decreasing the simpleness of therapy. In this system, the thoracic ROM for the patients is measured and presented in real time. The originality of this paper, as a first report of a developed prototype, is to demonstrate the effect of the visual biofeedback system in the chest expansion test.

II. System Design of Automatic Thoracic ROM Measurement System

A. Required functions

Required functions for measuring chest circumference are the following:

1) Should measure the time-series data of chest circumference in breathing (Required specification on resolution is better than 3 (mm))
2) Should be easy to attach the measurement device
3) Should be inexpensive

On the other hand, required functions for the feedback system are the following:

1) Should visualize a graph of about 60 (s) time-series data

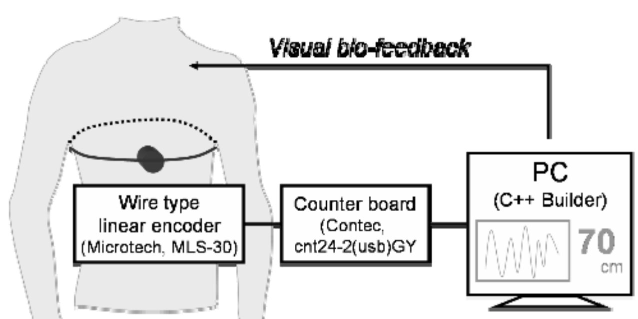

Fig. 1 Electrical system of automatic thoracic ROM measurement

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of chest circumference

2) Should visualize current chest circumference

3) Should be easy to operate the measurement system

B. Thoracic ROM measurement device

Based on the required functions stated in Section IIA, a wire type linear encoder (Microtech Laboratory Inc., MLS-30, resolution: 0.2 (mm), multiplication: 4) is selected as a sensor to measure the changes in chest circumference (See Fig. 1). As shown in Fig. 2, the wire is wrapped around the thorax such as at the area of the axilla and the xiphisternum. The detected chest circumference is measured using a counter board (USB connection, CONTEC, CNT24-2(USB)GY, sampling time: 50 (ms)). After that, the thoracic ROM, d_i, is calculated as follows:

$$d_i = MAX_i - MIN_i$$

where d_i is the thoracic ROM in i times breath, MAX_i is maximum chest circumference in i times' maximal inhalation and MIN_i is minimum chest circumference in i times' maximal exhalation (See Fig. 3).

C. Thoracic ROM Visual Biofeedback

Figure 4 shows an example of a presented GUI (C++ Builder) for the patient and physical therapist. In Fig. 4, the measured time-series data of chest circumference, current chest circumference, thoracic ROM in last breath, *d-last*, and average thoracic ROM, *d-avg*, are presented.

$$d - avg = \sum_{i=1}^{N} d_i \Big/ N$$

where N is the number of breaths taken during the measured training period.

Fig. 2 Chest circumference measurement device

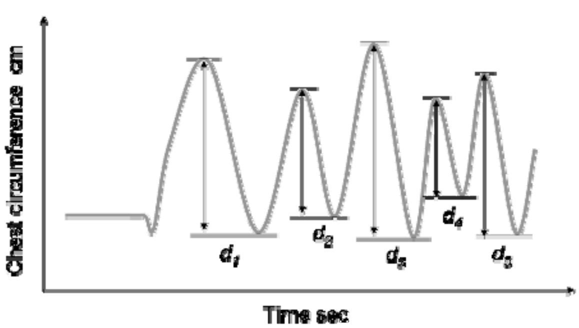


Fig. 3 Definition of thoracic ROM

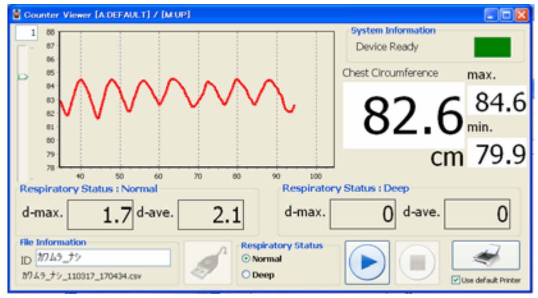


Fig. 4 Visual bio-feedback system

Fig. 5 Thoracic ROM training scene using biofeedback system

The interface screen is designed simply and intuitively. The physical therapist only enters the patient's name and clicks three times to measure the thoracic ROM and print out the data. The setup time to start measuring the thoracic ROM is within about 1 minute (See Fig. 5).

III. EVALUATION OF REPEATABILITY OF MEASURED THORACIC ROM

A. Objective

The objective is to analyze the repeatability of the thoracic ROM measured by the prototype of the linear encoder system.

B. Methodology

A physical therapist who was in charge of respiration rehabilitation attached the developed measurement device at the line of the axilla of a young healthy male. The subject drew a deep breath three times. This process, which included device attachment and deep breathing, was repeated twice. In this experiment, the subject drew breaths as deeply as possible.

C. Result and Discussion

TABLE 1 shows the result of the measured thoracic ROM. There is more than 5 (mm) difference between the *MAX* and *MIN* values in the 1st trial and those in the 2nd trial. This is because the position of the attached device is not exactly the same. However, the thoracic ROM, d, is almost the same. Therefore, the thoracic ROM, d, is not easily affected by differences in the attachment position. The thoracic ROM measured by the developed liner encoder system is enough for the required specification stated in Section IIA.

TABLE 1 Repeatability of measurement device

i	1st trial			2nd trial		
	d_i mm	MAX_i mm	MIN_i mm	d_i mm	MAX_i mm	MIN_i mm
1	44	865	820	45	869	824
2	45	866	821	49	874	825
3	45	869	824	43	876	833
Mean	45	866	822	46	873	827
S.D.	0.3	2.4	2.0	2.8	3.3	4.7

IV. Evaluation of Visual Bio-feedback of Thoracic ROM

A. Objective

The objective is to analyze the effect of real-time visual bio-feedback of measured thoracic ROM on the respiration and the thoracic ROM.

B. Methodology

Two healthy young males wore the measurement device at the xiphisternum. The subjects performed deep breathing strongly until they were tired. One subject (A) took a breath first with watching the bio-feedback screen and then without watching it. The other subject (B) took a breath first without bio-feedback and then with bio-feedback.

C. Result

Figure 6 (a) and Figure 6 (b) show the results of Subject A and Subject B respectively. TABLE 2 is the summarized data of the thoracic ROM. In both subjects, the thoracic ROM when bio-feedback was used was larger than that when bio-feedback was not used. Especially, in Subject A, a significant difference ($p<.05$, student t-test) was confirmed. In Subject B, variation in the thoracic ROM was larger when bio-feedback system was not used.

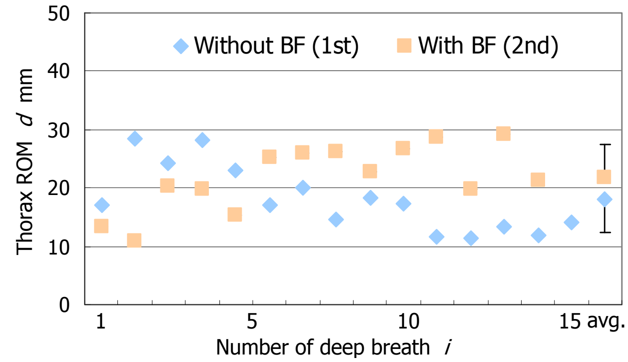
D. Discussion

When biofeedback was not used, the thoracic ROM decreased due to tiredness during the latter half of the deep breathing of both subjects.

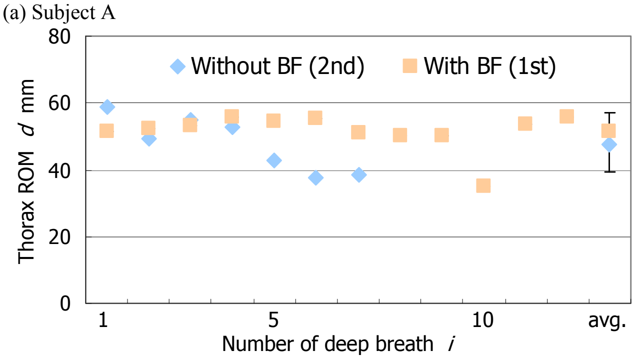
It was found to be easier to maintain a large and stable thoracic ROM during deep breathing by using real-time visual biofeedback system of the thoracic ROM.

V. Conclusion

Thoracic ROM is one of the simplest and most useful indexes to evaluate respiratory function. In this paper, we proposed the prototype of the thoracic ROM measurement system with real-time visual bio-feedback in the chest expansion test. Firstly, the repeatability and reliability of the thoracic ROM measured by a wire-type linear encoder was confirmed. Secondly, we analyzed the effect of bio-feedback system on the respiratory function. The result of the experiment showed that it was easier to maintain a large and stable thoracic ROM during deep breathing by using the real-time visual biofeedback system of the thoracic ROM.



(a) Subject A



(b) Subject B

Fig. 6 Effect of bio-feedback system on thoracic ROM. Note that error bars show the standard deviation.

TABLE 2 Thoracic ROM change by bio-feedback Note that Average ± S.D.

Subject	Without BF thoracic ROM d mm	With BF thoracic ROM d mm
A	18±5.6	22±5.7
B	48±8.3	52±5.6

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