

A Novel Device for Simultaneous Measurement of Nostril Air Flow Pressure and Temperature using Fiber Bragg Grating Sensor

Chethana K, Guru Prasad A.S, Omkar, Asokan S



Abstract: This paper presents the design, development, calibration and demonstration of non-invasive, Nostril Pressure and Temperature Measurement Device (NPTD) employing Fiber Bragg Grating (FBG) sensors for the simultaneous, accurate and real-time measurement of nostril air flow pressure and temperature which can aid in clinical diagnosis of nasal dysfunction and associated nose disorders. The unique design of NPTD enables the comfortable measurement of randomly varying air flow pressure and temperature of both the nostrils simultaneously. To calibrate the pressure and temperature readouts of NPTD, suitable and in-house calibration techniques have been devised and adopted. The NPTD developed can provide certain critical features such as breathing pattern, rate of respiratory, individual nostril temperature/pressure, nostrils dominance pattern, body core temperature etc., which can aid clinicians in early diagnosis of breathing problems associated with heart, brain and lung malfunctioning. The developed NPTD is simple in design, practically implementable robust, EMI proof and non-electric, which are obligatory features for any clinical diagnostic tool used in a hospital environment.

Keywords : Fiber Bragg Grating, Biosensor, Fiber Sensor, Nostril Air Monitoring, Healthcare.

I. INTRODUCTION

Breathing is an important part of physiological process that passage air in and out of the mouth and nose through lungs [1,2]. If one compares the breathing through mouth and nose, nose creates a higher air pressure and for that reason allows for a slower exhalation which gives the lungs spare time to intake larger amount of oxygen into the body [3]. The progression of breathing has two different phases, namely inspiration (inhalation) and expiration (exhalation). The expelled air has a higher pressure and temperature than the inhaled air due to the switching in the lungs and respiratory passage ways [4, 5].

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Measurement of nostril air flow pressure/temperature provides vital features like breathing pattern, respiratory rate, changes in individual nostril pressure/temperature, nostrils dominance, body core temperature etc. [6, 7]. The measurement of nostril pressure and temperature offers significant information, useful in the analysis of various breathing disorders and human thermoregulatory system [8-15]. Several important clinical procedures for treating disorders related to obstructive sleep apnea [7], sinus arrhythmia[4], hypopnea syndrome, stuffy nose and asthmatic [16] etc., are characterized by incidents of partial or complete obstruction of the flow of air (hypopnea), followed by transient awakening that leads to the restoration of upper airway permeability. Study of human breathing pattern plays an vital role in understanding and control of respirational diseases like obstructive sleep apnea [7], sinus arrhythmia [4], asthma [17] etc.

Further, real-time and accurate measurement of body core temperature has significant impact in understanding patient's thermoregulatory system and managing specific drug dosage during anaesthesia [14] and perioperative hypothermia [18]. Several studies have been undertaken on the importance of nostril dominance and changes in individual nostril temperature/pressure which can distress the autonomic nervous system, central nervous system (including cognition), and overall metabolic activities. The clinical trials on the application to angina pectoris and obsessive compulsive disorder are based on the variation in the nostril air flow [19, 20].

In addition, researchers have also suggested three advanced unilateral force nostril breathing techniques, first for stimulating the immune system; second for developing a comprehensive, comparative, and intuitive mind; and the third for developing an enlightened-transcendent mind [21]. According to the yoga science, variance of nostril air flow may play an important role and act as an indicator of the energy flow state in the human body [22-24]. It can be noted from the literature that the transient dominance of left and right nostrils has different effects and can be interpreted contrarily to relate to human body function/dysfunction. For example, during right nostril's dominance (Surya Swara or suryanadi), the mind favours the active senses (hand, feet, organs of procreation, elimination, and speech) which are favourable for undertaking action that require strength and mental determination [22,23].



Similarly, during left nostril's dominance (Chandra Swara or chandranadi), the mind favours the cognitive senses (taste, touch, sight, smell, and hearing) which are conducive for undertaking action that are restful, require receptivity [25,26]. Therefore, the measurement and real-time tracking of breathing pattern, respiratory rate, change in individual nostril pressure/temperature, body core temperature and nostril dominance is significant and important for the pulmonologist to study and help in treatment of respiratory disorders, human thermoregulatory system, etc. [8-15]. These studies can also aid in treating the sudden death syndrome in neonates acting as a precursor during critical intensive care [27].

There are several methods reported in literature which uses technologies like visual observation, impedance pneumography, acoustic sensing, respiratory inductance plethysmograph, respiratory belt transducer, nasal temperature prongs etc., for the measurement of breathing cycle parameters in hospital environment [28,29]. However, most of these techniques may adopt electrical transducers and direct contact to the skin, which are biomedically unsafe and may cause discomfort to the patients during investigative procedure.

Fiber Bragg Gratings (FBGs) are one among the most suitable and popular choices of technology, for use as sensors in biomechanical applications [30-34]. This paper presents an optical sensing methodology adopting FBGs for the development of a Nostril Pressure and Temperature measurement Device (NPTD). The developed NPTD is clinically tested for simultaneous measurement of breathing pattern, respiratory rate, nostril dominance, change in individual nostril pressure/temperature, body core temperature etc., which have clinical relevance in many pertinent fields of biomedical engineering.

II. DESIGN, DEVELOPMENT AND CALIBRATION OF NOSTRIL PRESSURE AND TEMPERATURE MEASUREMENT DEVICE (NPTD)

In this work, a total of four FBGs are used as pressure and temperature sensors (2 Bare FBGs as pressure sensors and 2 packaged FBGs as temperature sensors) which are integral part of the NPTD. The FBG sensors used in the present work are fabricated on a photosensitive fiber of 9/125 μ m diameter using the widely adopted phase mask technique [23]. Since the FBGs are simultaneously known to be sensitive to imparted pressure and surrounding change in temperature, it is pertinent to design independent and exclusive sensors for measurement of both pressure and temperature. The design criteria for NPTD, is to offer a biomedically safe and comfortable structural design with appropriate sensor instrumentation for easy and accurate measurement of nostril pressure and temperature [35,36].

2.1 FBG Temperature Sensor Probe in NPTD

As the fabricated FBG sensor is also responsive to changes in the nostril air flow pressure, proper compensation has to be adopted for explicit nostril air flow temperature measurement [37]. Figure 1 shows the picture of FBG temperature sensing probe used in the present study for explicit air flow temperature measurement. An aluminium tube of 200 μ m

inner diameter is used to encase the FBG sensor fabricated on a fiber of 125 μ m, whose one end is enclosed and the other end is pigtailed to the connecting fiber. This encasement will absorb the external pressure, shielding the FBG sensor and allowing it to react only to the external changes in temperature due to the thermo-elastic property of the stainless steel tube.

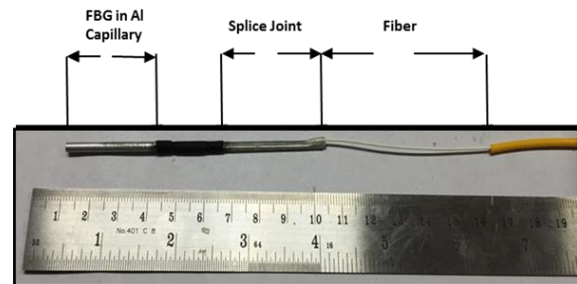


Fig.1: FBG Temperature sensor probe construction.

Before the use of the developed FBG temperature sensor probe, calibration trials have been carried out along with bare FBG sensors fabricated in the laboratory, whose temperature response is known a priori [38]. At the start of the calibration process, both bare FBG sensor and the developed temperature sensor probes (FBGT1 and FBGT2) are placed in the close vicinity on a flat metal plate and the temperature of which is raised in steps of 10C from 300C to 600C using a digital hotplate built with a temperature sensor (IKA-Werke, Germany) as shown in figure 2. Simultaneously, real-time responses of all the three FBG sensors are recorded through the FBG interrogator (Micron Optics SM 130-700). The changes in the centre wavelength of the bare FBG sensor and the FBG temperature sensor probes are plotted together to obtain the calibration factor. Figure 3 shows the scatter plot of change in wavelength of the two FBG temperature probes and the bare FBG sensor. From the plot, it can be seen that the responses of both bare FBG sensor and the FBG temperature probes are linear in the entire range of measurement and follow a common trend. From the linear fit of all the three curves the calibration factor of 10.4 pm/0C rise in temperature has been extracted for the bare FBG sensor which matches well with the reports in literature [39] and an average calibration factor of 8.16 pm/0C has been obtained for the developed FBG temperature probes (FBGT1 and FBGT2)

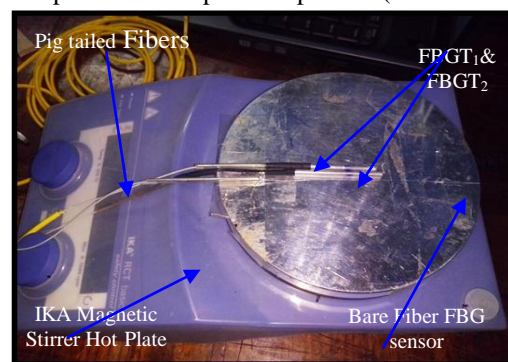


Fig.2: FBG Temperature probe calibration setup.

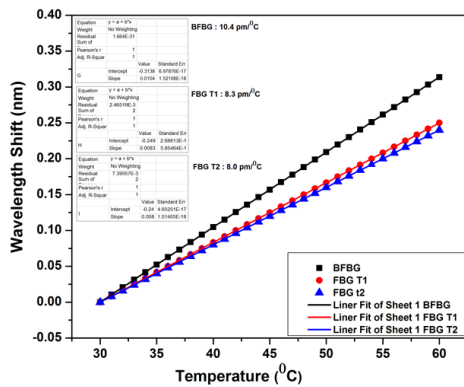


Fig. 3: Calibration graph of FBG temperature sensor probes

An important design criterion of the FBG temperature sensor probe is to retain the inherent fast response time of the FBG sensor for the temperature changes even after the encasement of the FBG sensor in the capillary tube. Hence, one of the FBG temperature sensor probes (FBGT1) is tested against a standard bare FBG sensor to understand its response time for instinctive temperature variations. For this purpose, random heat bursts using a hot air gun (Bosch Hot Air Gun, 1800w, Model: GHG600-3) are imparted on both bare FBG sensor and the developed FBG temperature probe (FBGT1).

Figure 4 shows the real-time plot depicting response of bare FBG sensor and one of the developed FBG temperature probe (FBGT1) for the five random air bursts imparted from hot air gun. It is to be noted that the random air bursts from the hot air gun generates both pressure and temperature variations on the sensors under test. However, the FBG temperature probe does not react to any pressure variations compared to the pressure sensitive bare FBG sensor which is evident from the huge difference in response (change in wavelength) of both the sensors.

From figure 4 it is evident that there is an instinctive lag in the response of the FBG temperature probe, which is minimal (~ 2 second) and is consistent over the illustrated three cycles of the temperature change, showing the reliability of the developed FBG temperature probe. However, in the context of sensing gradual change in temperature in the breathing activity, this lag is acceptable and can be ignored as it is consistent.

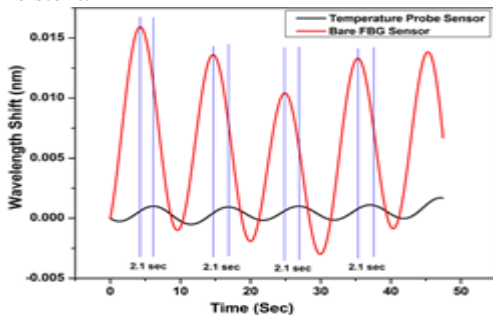


Fig. 4: Response time validation of FBG temperature probe

2.2 FBG Pressure Sensor in NPTD

The pressure sensors of NTPD consists of two equal sized metal rings with suitable distance between them anchored on a rigid metal frame, used for bonding two bare FBGs as shown in the schematic diagram of figure 5. The air coming

out from each nostril, independently impinges on the FBGs bonded on the rings causing impermanent physical deformation which changes the central wavelength of the FBG sensors. However, apart from reacting to changes in nostril air pressure, it will also naturally react to variations in temperature of the nostril air which needs to be compensated for the calculation of pure pressure effect. The shift in wavelength will be proportional to the imparted pressure within the elastic range of deformation of the photosensitive fiber in which the FBG sensor is inscribed.

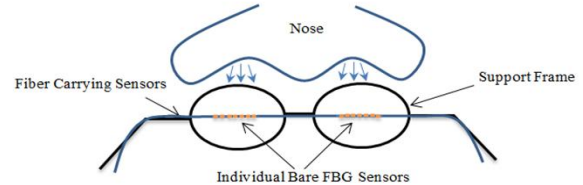


Fig. 5: Schematic diagram of the FBG nostril air pressure sensors.

To evaluate the performance and to calibrate the developed FBG nostril air pressure sensors, a customized pressure calibration setup is designed. Figure 6 shows the calibration setup which comprises of a commercial pressure sensor and a pressure actuation chamber. The calibration chamber consists of a flexible pressure actuation chamber which splits into two arms/passages of equal size. An electrical micro structure pressure sensor from Honeywell Pvt Ltd® (SCXL series) is used as the pressure sensor in the calibration chamber. One side of the arm is instrumented with the electrical pressure sensor, whereas the other side is loaded with the FBG nostril pressure sensor. The pressure in the actuation chamber can be increased by manually pumping the inflation bulb. Any pressure variation from the actuation chamber is equally divided in to two portions leading to identical pressure variation on both the sensors of the two arms.

Figure 7 shows the response of both electrical pressure sensor in X axis (mm of H2O) and relevant change in wavelength of the FBG nostril air pressure sensors in Y axis (nm) for manual increase in air pressure through inflation bulb. From the plot, it is apparent that response of both FBGs and electrical pressure sensors follow a common trend and the readings are matching well in the entire range of measurement. An average calibration factor of 4.78 pm/mm of H2O can be obtained from the calibration trials for the FBG nostril air pressure sensors which can be used to convert obtained wavelength shifts of the FBG nostril air pressure sensors to relevant pressure readings.

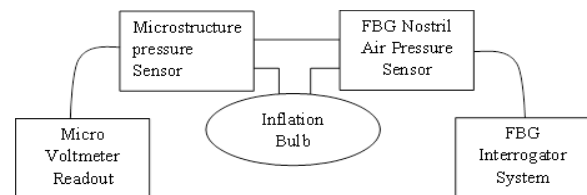


Fig 6: Calibration setup for FBG nostril air pressure sensor

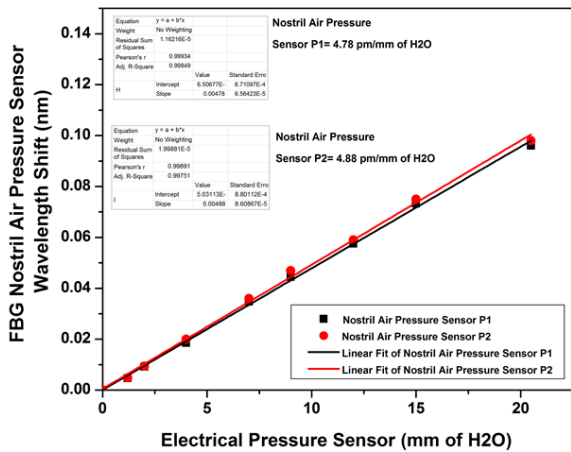


Fig. 7: The calibration graph of FBG nostril air pressure sensor.

III. EXPERIMENTAL DETAILS

3.1 Subjects

A set of eight volunteered subjects (3 female and 5 male) are considered for testing developed NTPD. Subject's age is spread between 22 and 28 years and are of varying Body Mass Index (BMI mean:25). Before starting the experiment, the necessary ethical procedures are followed and necessary approvals are obtained. The subjects are examined by a general medical practitioner a day prior to the trial and all of them declared to be in healthy condition to participate in the experimental trials.

3.2 Experimental Setup

As mentioned earlier, independent FBG sensors are developed and calibrated against commercial sensor for the measurement of nostril air pressure and nostril air temperature. These calibrated sensors are suitably mounted on a head support to fit on to the subject with least discomfort as shown in figure 8. A pictographic representation of NTPD mounted on a volunteered subject along with its fibers connected to a 4-channel FBG interrogator (SM 130-700, Micron Optics) is illustrated in figure 9 [40].

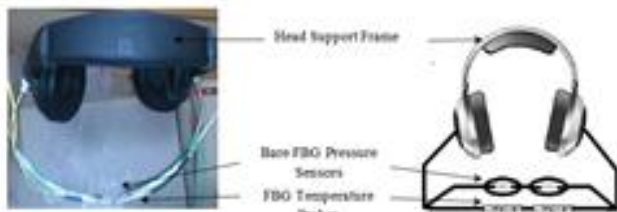


Fig. 8. Photograph and schematic diagram of the developed FBG based NTPD.

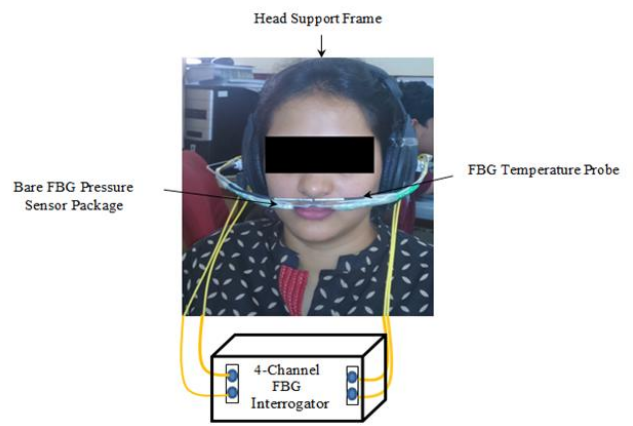


Fig.9: Experimental setup for testing FBG based NTPD

3.3 Methodology

The developed NTPD is evaluated to simultaneously measure pressure and temperature of nostril air flow through a suitable experimental methodology. Experimental trials are sequentially conducted on all the eight volunteered subjects with prior instructions on the protocol/procedure of the trials.

The developed NTPD is mounted on the subject's head such that all the four FBG sensors are positioned symmetrically below the right and left nostrils. Figure 10 shows the details of the breathing patterns where subjects are advised to adhere to normal breathing pattern for first 60 seconds, slow breathing (Bradypnea) for next 60 seconds and fast breathing (Tachypnea) for the last 60 seconds of the experiment in sitting posture. Further, real-time changes in wavelength of all the FBG sensors (2 Nostril air pressure and 2 Nostril air temperature sensors) are recorded and suitably processed in time and frequency domain to extract breathing pattern, respiratory rate, nostrils pressure and temperature air flow, nostril dominants, body core temperature etc.

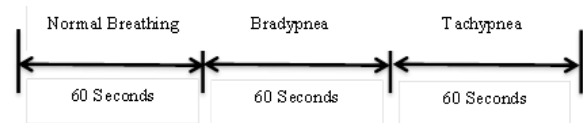


Fig.10: Breathing protocol adopted in the experimental trials

IV. TEST RESULTS AND DISCUSSION

The calibrated FBG nostril air pressure and nostril air temperature sensors of NTPD are experimentally tested on eight volunteered subjects with the devised experimental facility and adopted testing protocol. For the purpose of illustration, the results of a typical subject is detailed and discussed to evaluate performance criteria of the developed NTPD towards meeting the objectives of the work. Further, this real-time data is presented in three different sections each defining the method of measurement of nostril air pressure, nostril air temperature and the frequency of breathing activity occurrence.

Figure 11 and figure 12 show the real-time response of two calibrated nostril pressure sensors and two calibrated nostril temperature probes (both left and right) of the NTPD for the breathing protocol adopted in the present work. Since the effect of individual nostril temperature can be obtained from developed FBG nostril air temperature probe, this value is adjusted in the readings of the nostril air pressure sensor which essentially is a combined effect of nostril pressure and temperature, to obtain an instinctive nostril air pressure value which is shown in figure 11.

It is evident from figure 11 that there are three distinct sections depicting normal breathing (0-60sec), voluntary bradypnea (60-120sec) and voluntary tachypnea respectively (120-180sec) which matches well with the adopted protocol of the experiment. It can be seen from all the four plots of figure 11 and figure 12 that the trend of the left and right nostrils of both FBG nostril pressure and FBG nostril temperature are similar and consistently following each other providing enough evidence to justify performance of the developed NTPD. Any possible variations in the magnitudes of the measured individual nostril pressures/temperature or evidence of nostril dominance can be clinically accounted for meaningful diagnostic conclusions to aid in treating disorders related to breathing.

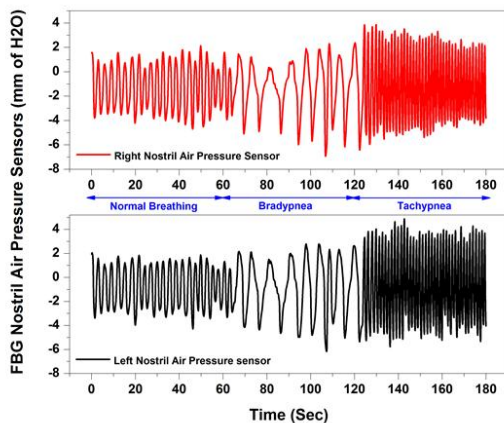


Fig.11: The response of left and right FBG nostril air pressure sensors for varying breathing pattern

For extracting the breathing rates simultaneously in each of the three different types breathing patterns (Normal, Bradypnea and Tachypnea) experimented in the present study, real time signal of FBG nostril air pressure sensor is processed in frequency domain. Figure 13 shows the frequency domain plots of the left and right FBG nostril pressure sensors. From both the plots of the figure 13, it is evident that during normal breathing, the dominant frequency observed is around 0.34 Hz which accounts for 20.4 beats/min which is a normal range of breathing activity for healthy human beings [41,42]. Similarly, for bradypnea and tachypnea, the dominant frequencies lie around 0.14 Hz and 0.7 Hz which accounts for slow breathing rate of 8.4 beats/min and fast breathing rate of 42 beats/min respectively. Similarly, signals from all the eight volunteered subjects are processed to extract breathing rates during normal breathing, bradypnea and tachypnea which are shown in table 1. Further, the mere existence of common dominant frequencies from

both left and right nostril sensors in figure 13 indicates the efficacy of the measurement using the developed NTPD.

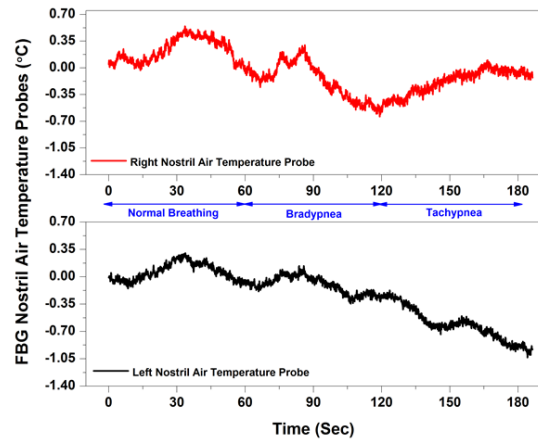


Fig.12:Response of left and right FBG nostril air temperature sensors for varying breathing pattern.

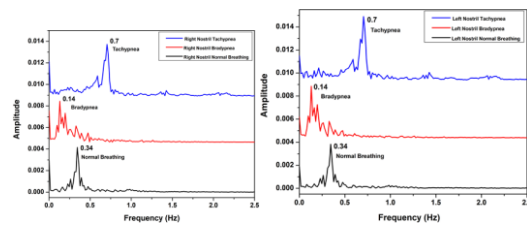


Fig. 13: Frequency domain representation of the FBG nostril air pressure sensors for extraction of breathing rate.

Table 1: Quantitative analysis of eight subjects to extract breathing rates during normal breathing, bradypnea and tachypnea.

Subjects	Normal Breathing	Bradypnea	Tachypnea
1	20	8	42
2	14	7	44
3	16	8	40
4	18	6	45
5	12	9	38
6	15	6	46
7	17	10	48
8	19	7	37

V. CONCLUSION

The present work demonstrates an inherently safe measurement device based on Fiber Bragg Grating sensor for the simultaneous, accurate and real-time measurement of nostril air flow pressure and temperature to aid in clinical diagnosis of nasal dysfunction and associated nose disorders. The unique design of the developed Nostril Pressure and Temperature measurement Device (NPTD) enables the comfortable measurement of randomly varying air flow pressure and temperature of both the nostrils simultaneously.



An in-house calibration setup has been developed to calibrate and test NPTD against a commercial pressure sensor and the results obtained are found to be in good agreement. The results of this study has several important clinical implications for treating disorders related to obstructive sleep apnea, sinus arrhythmia, hypopnea syndrome, stuffy nose and asthmatic etc., which are generally characterized by evaluation of critical parameters of breathing pattern. The unique findings of breathing cycle like breathing pattern, respiratory rate, nostril dominance, change in breathing pressure and temperature, body core temperature etc., has clinical relevance in many pertinent fields of biomedical engineering.

Disclosures

The authors disclose here that we no relevant financial interests in this article and neither any potential conflicts of interest.

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