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Continuous infrared thermometry of the nasal mucosa*

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SUMMARY *This study aims to continuously measure nasal mucosal temperature without interruption of nasal breathing using infrared thermometry. An infrared thermometer (Medi-Therm 310; Everest Interscience, Inc.) was directed at the nasal septum from a distance of 15 cm. Infrared radiation was continuously collected, then converted to an electrical signal proportional to the mucosal temperature and output to a chart recorder. In 70 subjects the mean nasal mucosal temperature was 30.4±2.0°C on inspiration and 32.0±1.8°C on expiration. Using multiple regression, nasal mucosal temperature was significantly related to atmospheric temperature ($p<0.0001$) and inversely related to the airway patency of the ipsilateral nasal passage ($p<0.05$).*

Key words: nasal mucosa, nasal temperature, infrared thermometry

INTRODUCTION

Inspired air is warmed and moistened during its passage through the nose and on expiration saturated heated air gives up both water and heat to the relatively cooler, drier nasal lining. The nasal mucosa is very efficient in these respects and the temperature of the mucosa is critical in enabling the mucosa to act as a heat and moisture exchanger.

The temperature of the nasal mucosa has been measured with mercury thermometers (Alwens, 1906; Krukower, 1929), thermocouples (Mudd and Grant, 1921; Winslow and Greenburg, 1932) and thermistors (Flisberg and Ingelstedt, 1962). These devices come into contact with the nasal mucosa, disturb normal nasal breathing (Drettner, 1961) and irritate the mucosa. Akerlunde and Bende (1989) measured the influence of the trauma of a contact electronic thermometer. After 5 min of intermittent consecutive measurements, made every 15 s, the temperature rose 3.4°C and after 5 min of continuous application the temperature rose about 9°C.

Cobet (1926) pointed out the advantages of a radiation method for measuring the temperature of the nasal mucosa. Using a radiation method, temperature measurements are possible without direct contact with a surface and the method is more accurate than measurements made with contact devices (Stoll and Hardy, 1949). Drettner (1961) pioneered such a radiation method to measure nasal mucosal temperature. A cone attached to a radiometer was inserted into the nasal passage and measurement was possible without contacting the mucosa. Subjects breath held during the measurement and a single reading was taken 10 s after the onset of apnoea. Of interest would be the measurement of the mucosal temperature throughout as near-normal nasal respiration as possible. This study aims to develop continuous measurement of nasal mucosal temperature without interruption of nasal breathing using infrared thermometry.

MATERIAL AND METHODS

Methods

A thin-walled plastic speculum, 12 mm long, is placed in the nasal vestibule to view the nasal septum. The speculum is conical and of 13-mm diameter at the narrow end closer to the septum and of 14-mm diameter at the other. A calibrated infrared thermometer (Medi-Therm 310; Everest Interscience, Inc.) is directed at the nasal septum at the level of the piriform aperture from a distance of 15 cm. A spot of light on the mucosa of 4.6-mm diameter indicates the field of view. Infrared radiation is continuously collected, converted to an electrical signal proportional to the mucosal temperature, and then output to a chart recorder (Figure 1).

No instructions are made to the subjects during recording, but it is checked to see they continue to breathe in the same nasal fashion they did without the speculum. Recording starts once the subject is settled (Figure 2). The minimum temperature recorded during a respiratory cycle corresponds to the end of inspiration and the maximum tem-

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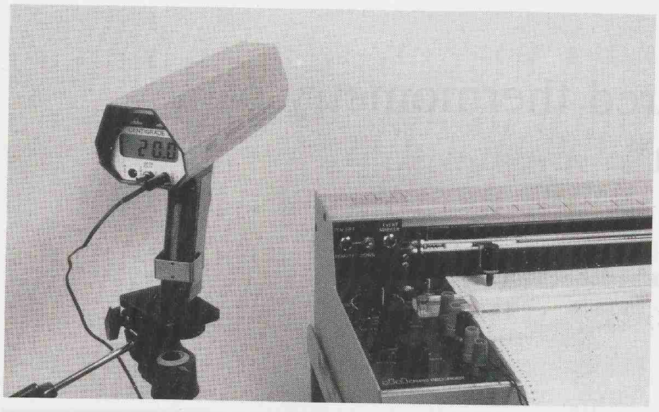

Figure 1. Infrared thermometer (Medi-Therm 310; Everest Interscience, Inc.) output to chart recorder. The spot of light indicates the field of view of the infrared thermometer.

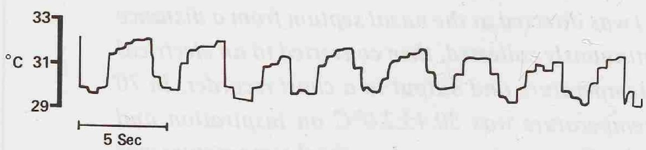

Figure 2. Chart recording of variation in nasal mucosal temperature with phases of respiration. The subject is at rest and breathing nasally. Peak temperatures correspond with end of expiration, minimum temperatures correspond with end of inspiration.

perature to the end of expiration. The temperature of the nasal mucosa on expiration is calculated as the mean of the maximum temperatures recorded in five consecutive respiratory cycles. The temperature of the mucosa on inspiration is similarly calculated as the mean of the minimum temperatures recorded in five consecutive respiratory cycles.

All objects emit infrared radiation. Infrared energy is generated by the vibration and rotation of atoms and molecules within a substance. As an object becomes hotter, its molecular activity increases and causes the object to generate more infrared radiation. Like other wavelengths of electromagnetic radiation, when infrared energy strikes an object it may be reflected from that surface, transmitted through the surface, or absorbed into that surface. A perfect absorber is called a "blackbody". A blackbody absorbs all of the radiation incident on it. A blackbody is not only a perfect absorber but a perfect emitter as well. Emissivity is a measure of the ability, or ease, at which an object, or surface, emits infrared radiation. Emissivity is the ratio of the radiant energy emitted by an object at a temperature T and the radiant energy emitted by a blackbody at the same temperature T (Kruse, 1963). The rate at which an object emits electromagnetic energy may be expressed as:

$$w = \sigma \cdot \varepsilon \cdot T^4$$

where w designates W/cm^2; σ is the Stefan-Boltzmann constant; ε represents the object's emissivity; and T is the object's surface temperature in degrees Kelvin. If the emissivity of the nasal mucosa is known, an accurate measurement of w leads directly to an accurate determination of the nasal mucosal temperature. When examined spectrophotometrically, the emitted infrared energy is found to lie in a broad band of wavelengths, whose maximum is given by Wien's displacement law as:

$$\lambda_{max} = 2{,}898 \cdot T^{-1}$$

in which the wavelength λ is expressed in μm. Since human nasal mucosa, in a comfortable room ambient, is normally at a temperature of approximately 303 K (i.e. 30°C) it should, according to the above expression, emit infrared with a maximum around 10 μm.

Drettner (1961) described the emissivity value for nasal mucosa as approaching unity. In the present study five freshly resected inferior turbinates were placed on a thermostatically controlled surface. The temperature of the exposed surface of mucosa was measured with both a heated thermocouple (Roeser et al., 1930; Sasaki, 1950) and an infrared thermometer and the emissivity value of the mucosa calculated as 0.975±0.005. Although the heated thermocouple is suitable for measuring the temperature of the mucosa *in vitro, in vivo* it cannot be used as it intermittently contacts the mucosa and causes irritation.

The radiation intensity from a surface decreases in inverse proportion to the square of the distance from the surface. On the other hand, the target size increases with the square of the distance between the thermometer and the object being measured. Therefore, as long as the object to be measured completely fills the field of view of the infrared thermometer, then the same temperature will be read, whatever the distance between the infrared thermometer and the object. To show the operator the exact field of view, the Medi-Therm 310 uses visible light which pulsates through the optics. The presence of the nasal speculum did not influence the measurement of the nasal mucosal temperature provided the spot of light, illuminated the nasal mucosa alone and no part of the speculum.

It can be derived mathematically that, where there is a constantly changing temperature, the measured value as plotted will generally differ from the true value by a value depending on the rate of change and both the time constant and damping ratio of the measuring apparatus (Adams, 1975). For the apparatus used the input is oscillatory, and can be taken as sinusoidal since any oscillatory signal of repetitive form may be expressed as the sum of sinusoidal signals, each of different amplitude and frequency. The time constant and damping ratio of the apparatus can be determined by measuring the response of the apparatus to a step-input (Adams, 1975).

Consideration was given to the error in measurement of the nasal mucosal temperature. A set of duplicate readings was obtained by measuring each member of a sample of 20 subjects twice, with a 20-min interval between the two readings. The measurement error can be presented in a number of ways, in this instance the standard deviation of the measurement error was calculated (Bland, 1987).

Material

To assess the influence of individual and environmental factors, 58 subjects were studied. Subjects were patients assessed on the day prior to surgery. Thirty-three were admitted for nasal surgery, 25 were admitted for minor ear or throat surgery. There were 47 men and 11 women. Their median age was 34 years (range 17-75 years). Age, sex and height of individuals were recorded. Nasal mucosal temperature recordings were taken from one nasal passage and, then, from the other nasal passage. The patency of the nasal airways was measured using the peak nasal inspiratory flowmeter (PNIF; see Youlten, 1933), three readings were taken, results were analysed by taking the highest of the three readings. The patency of both nostrils together, and then each nostril alone was assessed by occluding the other nostril with a cotton wool plug. The ambient temperature was recorded at the time of each individual's measurements. The relation between individual and environmental factors and nasal mucosal temperature was analysed by multiple regression (SPSSX; see Nie et al., 1975).

RESULTS

Figure 3 shows the response to a step input of a temperature change of 12.0°C, i.e. changing the target measured by the radiometer instantaneously from a cool target (20.9°C) to a warmer target (32.9°C). Mean values of five responses were calculated. The damping ratio was calculated as 0.64 and the response time as 0.24.

The true value of the maximal mucosal temperature will be 0.008°C greater than that recorded and correspondingly the true value of the minimal mucosal temperature will be 0.008°C less than that recorded. The standard deviation of the measurement error was 0.70°C. The mean nasal mucosal temperature was 30.4±2.0°C upon inspiration and 32.0±1.8°C upon expiration in the 58 individuals.

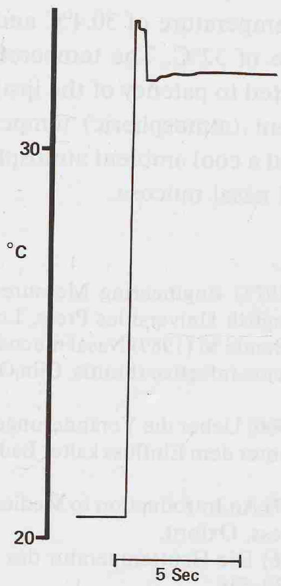

Figure 3. Chart recording of response of apparatus to a step-input of an increase in temperature of 12.0°C.

Table 1. Multiple regression analysis of predictor variables relating to nasal mucosal temperature.

variables	coefficients	standard error	t-ratio
age	–0.002	0.011	0.15
sex	0.598	0.378	1.58
height	02026	0.047	0.56
ambient temperature	0.480	0.071	6.74**
PNIF reading	–0.008	0.004	2.07*

PNIF: peak nasal inspiratory flowmeter; *: $p<0.05$; **: $p<0.0001$. F-test: 12.24 (df=5 and 110), $p<0.0001$

Table 2. Reduced model of multiple regression analysis of predictor variables relating to nasal mucosal temperature.

variables	coefficient	standard error	t-ratio
ambient temperature	0.490	0.071	6.89**
PNIF reading	–0.008	0.004	2.12*

PNIF: peak nasal inspiratory flowmeter; *: $p<0.05$; **: $p<0.0001$. F-test: 29.0 (df=2 and 113), $p<0.0001$

Table 1 shows the significance of predictor variables for nasal mucosal temperature by multiple regression. Table 2 shows the reduced model, after elimination of non-significant variables. Analysis by multiple regression showed mucosal temperature was significantly related to atmospheric temperature ($p<0.0001$) and inversely related to the airway patency of the ipsilateral nasal passage ($p<0.05$). The cooler the atmosphere, and the more patent the nasal airway, the cooler the mucosa. There was no association between the individual's age, sex and height and mucosal temperature.

DISCUSSION

This technique is the first to describe a method of continuous nasal mucosal temperature measurement throughout nasal respiration. The response time of the apparatus is sufficiently short to ensure no appreciable lag in measuring the respiratory cyclical changes of nasal mucosal temperature. As the infrared thermometer neither touches the mucosa nor is directly connected to the nose, it neither irritates the mucosa nor prevents nasal respiration.

The emissivity of the mucosa was found to be 0.975. As Drettner (1961) indicated if the mucosa is wet it should not significantly affect the readings. The emissivity of water is 0.97, and the infrared thermometer will be looking through this thin layer of water to mostly look at the mucosa beneath such that the thin layer of moisture will affect the reading even less.

The standard deviation of the measurement error was 0.7°C. The technique may not therefore seem to be too precise but factors other than the method will lead to variation not least the effect of the nasal cycle but also the regular cyclic fluctuation of blood flow to the mucosa which is known to occur in all tissues. Registered rhythmic oscillations are well known from investigations with the laser Doppler flowmeter (Olsson et al., 1985). They are most likely indications of vasomotion, which are at least partly dependent on sympathetic neurogenic activity (Olsson et al., 1986).

The atmosphere is composed of gases, liquids, and solid particles, all of which attenuate the transmission of infrared radiation either by absorption or scattering the radiation. Water and carbon dioxide are the most important absorbing molecules. The spectral range measured by the infrared thermometer is 8–14 μm. A probe working in this range will reject unwanted energy from sunlight and high-intensity lighting. This range also avoids most of the water and carbon dioxide molecular-absorption bands to ensure maximum signal conditions, but some attenuation still occurs such that calibration of infrared systems does vary with atmospheric-path length and humidity.

Although the path length in the described technique is short and calibration of the instrument takes place at typical room humidity, at the end of expiration the air at the nostrils has almost 100% relative humidity (Ingelstedt, 1956), and a carbon dioxide content of 5.6% compared with a usual content in room air of 0.03% carbon dioxide (Nunn, 1977). The increased water and carbon dioxide in the expired air might be expected to attenuate the infrared radiation emitted from the mucosa. If the infrared thermometer is set up to view an object of constant temperature through a path of alternating inspiratory and expiratory gases a fixed temperature is read, indicating infrared radiation is not attenuated to any measurable extent by expiratory gases in this technique. To date estimates of mean nasal mucosal temperature have been from 29.2°C (Winslow et al., 1932) to 34°C (Mudd et al., 1921). Presumably, the variation had arisen from not just differing techniques and the degree to which the contact device irritated the mucosa but also to different conditions including the subject's ability to breathe nasally or orally.

Using small thermo-junctions, Cole (1954) found the mucosal surface temperature varied in time with the respiratory cycle. On cessation of nasal breathing it was found to be about 30°C after an inspiration and about 32°C immediately after an expiration.

Drettner (1961), the first investigator to use infrared thermometry, measured the temperature after a fixed period of apnoea of 10 s. The temperature of the mucosa rose during this apnoeic period by usually about 1°C at room temperature. Subjects were asked to start a period of apnoea immediately after a slight inspiration. The mean of the right and left nasal passages was in normal men and women 32.9°C. Given that this temperature is about 1°C higher than at the onset of apnoea, the measured mean temperatures in the present study of 30.4°C on inspiration and 32.0°C on expiration are in general agreement with the values recorded by both Cole (1954) and Drettner (1961). The lowest and highest nasal mucosal temperatures in the present study were 25.2°C and 35°C respectively. These values differ from those given by Drettner (1961), viz. 28.4°C and 35.1°C and those given by Fabricant (1957), viz. 29.7°C to 34.7°C, and Urban (1958), viz. 26.1°C to 37.0°C. The measurements in the latter two investigations were made with thermo-elements during apnoea. Estimates of minimal nasal mucosal temperature were lower in the present study, presumably because the technique neither irritated the nasal mucosa nor interferred with the cooling effects of nasal inspiratory airflow and the apparatus had no appreciable lag in temperature measurement.

The relationship between nasal mucosal temperature and the temperature of the ambient atmosphere has been described by previous investigators. With deliberate cooling of the inspiratory air to about −2°C, Drettner (1961) observed a fall in the nasal temperature of between 3.9°C to 6.4°C. The environment may influence the temperature of the nasal mucosa in two ways: either by temperature changes of the skin (Alwens, 1906; Spiesman, 1936), or directly by inspiring ambient air. In the present study it was ensured all subjects were comfortably clad, feeling neither hot nor cold; changes in nasal mucosal temperature with ambient temperature were therefore attributed to the direct effect of inspiring air rather than through changes in skin temperature.

The study confirms the relationship between the patency of the nasal passage and the temperature of the ipsilateral nasal mucosa first noted by Drettner (1961). He found that the side of the nose which appeared at rhinoscopy to be the wider had a tendency to have the lower temperature and vice versa. The reason for this relationship is attributed to a cooling effect on the mucosa from the inspiratory air; this effect being more pronounced in the nasal cavity with the wider passage.

A new technique of continuous non-contact recording of nasal mucosal temperature during nasal breathing has been described. This should prove applicable to studying aspects of nasal physiology and pathology. Measurements in a group of ENT patients showed a mean inspiratory nasal mucosal temperature of 30.4°C and a mean expiratory temperature of 32°C. The temperature of the nasal mucosa was related to patency of the ipsilateral nasal passage and ambient (atmospheric) temperature; a patent nasal passage and a cool ambient atmosphere were associated with a cool nasal mucosa.

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