ORIGINAL CONTRIBUTION

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Dynamic infrared thermography of the nasal vestibules: a new method*

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SUMMARY

Objective: *The surface temperature distribution within the nasal vestibule and the nasal cavity strongly depends on the exact intranasal detection site and point of time during the respiratory cycle. Therefore, conventional temperature measurements e.g. with thermocouples only provide selective measurements. The use of infrared thermography cameras could present a new contactless method with a high spatiotemporal resolution. The aim of the present study was to evaluate the use of infrared thermography camera systems for measurements of the nasal surface temperature during respiration.*

Methods: *The surface temperature profiles within the nasal vestibules of healthy volunteers were recorded with infrared thermography cameras during several breathing cycles. Two different types of infrared thermography standard systems were used.*

Results: *The recordings allowed a display of temperature alterations within the nasal vestibules in a high spatiotemporal resolution synchronous to the breathing cycle. During inspiration, the vestibular surface cooled down presenting a non-homogenous distribution (range, 24.7 to 30.2 °C). During expiration, the vestibular surface was warmed again with a non-homogenous distribution (range, 33.1 to 36.2 °C). The results of both camera systems were comparable.*

Conclusion: *Infrared thermography cameras allow the exact mapping of nasal surface temperature within the nasal vestibules with a high spatiotemporal resolution without surface contact.*

Key words: infrared thermography camera, nasal temperature, nasal air conditioning, vestibular skin

INTRODUCTION

One of the main functions of the nasal mucosa is the humidification and warming of the inhaled air in order to ensure an ideal pulmonary gas exchange and to protect the lower respiratory tract [(1)]. During the respiratory cycle a heat and humidity exchange between nasal mucosa and respiratory air takes place [(2)].

The temperature changes of the nasal mucosa vary depending on airflow patterns and the point of time during the respiratory cycle [(2)]. In areas of turbulent airflow, temperature changes are more pronounced compared to areas of laminar airflow. In particular the anterior nasal segment plays an important role in nasal air conditioning [(3,4)]. When it comes to in vivo temperature measurements of the nasal mucosa the precise intranasal detection side and point of time during the respiratory cycle are essential [(2)]. The reference method for intranasal temperature measurements of the mucosa is the application of a miniaturized thermocouple [(2,5,6,7)]. Its outer diameter amounts to less than half a millimeter. The response time varies between 0.1 and 0.4 seconds [(8)] and allows temperature recording synchronous to breathing without causing relevant irritations [(2,5,6,7)]. However, only point measurements can be recorded while the direct contact with the surface during the measurement may slightly influence the result. In order to provide a precise and entire temperature mapping of the nasal mucosa infinite measurements would be necessary. Within this context, numerical computer simulation are crucial, yet the results strongly depend on the applied boundary conditions [(9)].

Intranasal temperature recordings with infrared thermography camera systems could provide a novel dynamic contact-free temperature mapping with a high local and temporal resolution. Therefore, the aim of the present study was to evaluate the use of two different commercially available infrared thermography camera systems for contact-free temperature measurements of the nasal vestibules during respiration. The study was performed to test the feasibility of the technical set-up using a dynamic infrared thermography camera system.

MATERIALS AND METHODS

Imaging

Thermography or thermal imaging is a particular kind of infrared imaging system allowing the quantification of surface

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temperatures of different materials in high local and temporal resolution. These cameras detect heat radiation as an electromagnetic radiation in the range of the infrared spectrum. Depending on the emission degree, which is unique for each material, room temperature and humidity, it is possible to measure the surface temperature with an absolute accuracy of +/- 2 °C. Due to the relative accuracy of 40 mK, minor temperature differences are detectable. Thermography camera systems work with a measurement frequency of up to 100Hz, depending on the thermography camera. More than 100000 pixels can be detected simultaneously.

In our study two different camera systems had been applied. The camera system Pyroview 380L (DIAS infrared GmbH, Dresden, Germany) was used (camera 1) with a frequency of measurement of 50 pictures per second and a resolution of 384 x 288 pixels. The relative exactness amounts to 80mK. The camera system TVS 500 ex (Goratec Technology GmbH, Erding, Germany) (camera 2) was applied with a measurement frequency of 60 pictures per second and a resolution of 320 x 240 pixels. The relative exactness is declared as less than 50mK. The study was not sponsored or supported by one of the manufacturing companies.
With these two camera systems, measurements were recorded from two healthy subjects with no objective nasal pathologies or subjective nasal problems. After giving their written informed consent to participate in the study, a thorough history and clinical examination including anterior nasal endoscopy were taken of each volunteer. The measurements were carried out at a room temperature of 21°C with a relative humidity of 15%.

The emission degree was chosen according to the camera manuals (for the human skin: 0.98). The measured temperatures were checked with a high precision digital contact thermometer on the cheek skin. In both camera systems, the measured values exactly corresponded to the values measured by the contact thermometer. After successful calibration of the camera systems concerning emission degree, room temperature and humidity, temperature changes within the nasal vestibules during quiet nasal breathing were simultaneously recorded. The head of the subjects was fixed on a head holder (Figure 1a and 1b).

For visualization of the temperature results, every pixel was converted in a defined shade of colour according to the measured temperature. The graduation of colours can be selected by the thermography camera software. An artificial colour picture is created in this way. Two different colour schemes were used: 38°C was coded in red, 26°C in dark blue and the range between these temperatures was represented by a non-graded junction of red and dark blue. Furthermore, prismatic colours for the range between 20°C and 39°C were selected.

RESULTS

Dynamical measurement of changes in nasal surface temperature within nasal vestibules was feasible with both infrared thermography camera systems. Both systems were easy to use and showed comparable results.
At the beginning of inspiration the surface temperature was cooled down. This cooling reached a plateau like phase until the end of inspiration for the remaining length of time of inspiration (Figure 2 and 4). Additionally, at any particular time of inspiration a particular temperature distribution could be observed. The surface temperature ranged from 30.2°C at the beginning of inspiration to 24.7°C at the end of inspiration depending on the exact point of time during inspiration and the exact detection site within the nasal vestibule.
A pronounced warming of the nasal surface within the vestibule took place at the beginning of expiration. During the remaining length of time of expiration, the temperature was approximately constant. Again, an uneven temperature distrib-

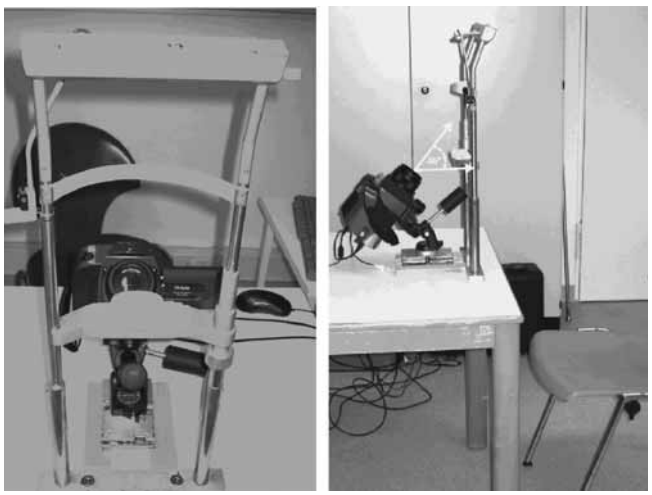

Figure 1a and 1b. Technical set-up with the infrared thermograph camera fixed on a table and the head holder from the point of view of the volunteer (a) and from the side view (b).

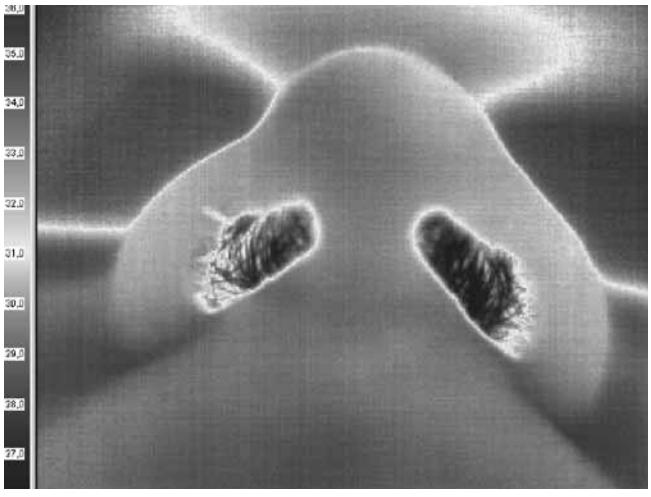

Figure 2. Thermal image of the endinspiratory status taken with camera 1 (Pyroview 380L). The surface temperature in °C is presented correspondingly to the grey scale of the figure.

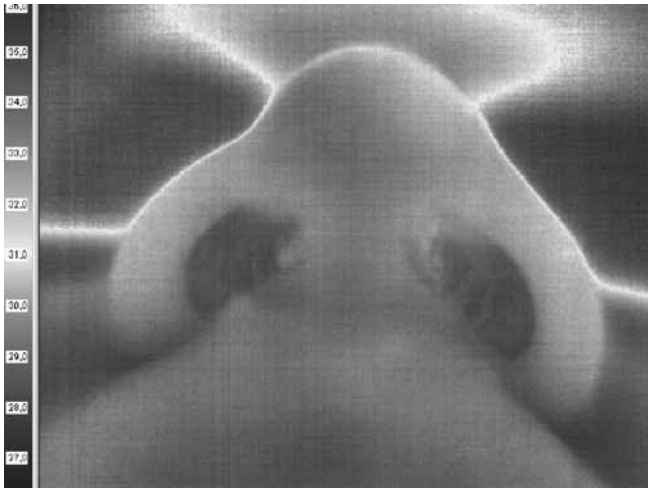

Figure 3. Thermal image of the endexpiratory status taken with camera 1 (Pyroview 380L). The surface temperature in °C is presented correspondingly to the grey scale of the figure.

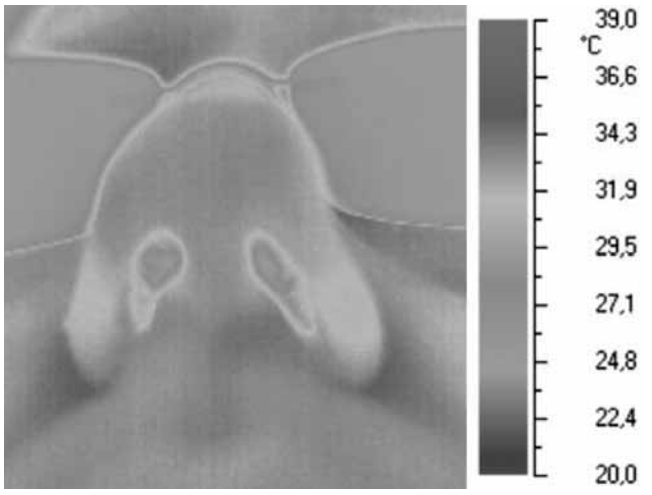

Figure 4. Thermal image of the endinspiratory status taken with camera 2 (TVS 500 ex). The surface temperature in °C is presented correspondingly to the grey scale of the figure.

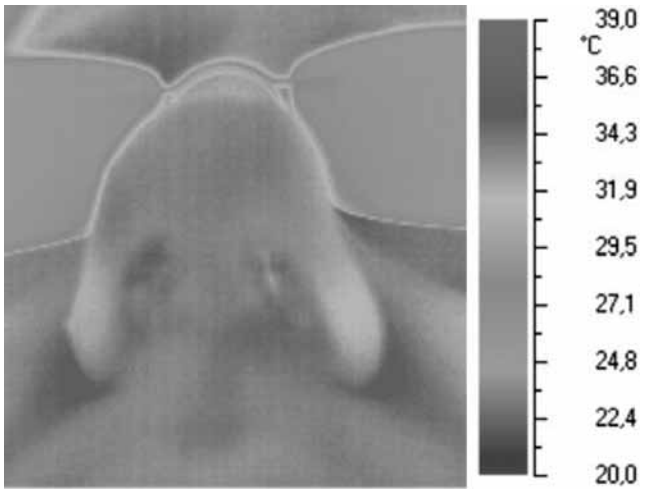

Figure 5. Thermal image of the endexpiratory status taken with camera 2 (TVS 500 ex). The surface temperature in °C is presented correspondingly to the grey scale of the figure.

ution at any point of time during expiration could be observed (Figure 3 and 5). The temperature ranged from 33.1°C at the beginning to 36.2°C at the end of expiration.
The described temperature changes occurred during each nasal breath depending on breathing frequency and the duration of each breath altering temperature profile accordingly.

DISCUSSION

The most important reference method for intranasal temperature measurements of the nasal mucosa currently is a miniaturized thermocouple with a very small outer diameter and a very short response time [2,5-7]. The main problem in the use of thermocouples is that only point measurements are possible and a complete temperature mapping of the nasal mucosa cannot be provided due to the complex three-dimensional nasal anatomy. Additionally, infinite single measurements would be required to provide an entire temperature profile.
With the help of two conventional infrared thermograph camera systems, the temperature fluctuation on the intranasal surface within the nasal vestibule during quiet breathing had been recorded. The two systems were equally easy to apply and similar results could be obtained. The intranasal surface temperatures had been visualized in two dimensions. For the first time, a complete temperature mapping of the surface within the nasal vestibule could be achieved. The temperature values depend on the point of time within the respiratory cycle and on the exact intranasal detection site. The measurements had been non-invasive and did not present any hygienic problems.

In various aspects the infrared camera proved to be a very useful instrument for intranasal temperature measurements. One major advantage is the contactless temperature recording.
Using infrared thermography, changes in the nasal surface temperature can be detected without any influences and methodological artifacts related to the contact between sensor and nasal surface.
Within static measuring conditions without periodic changes in temperature this problem might be disregarded. In the case of a dynamic measurement, for instance, the surface temperature during a complete respiratory cycle or the measurement at a given time during breathing, the result accuracy is limited.
The advantage of contactless measurements with the infrared thermometer has already been described by Willat in 1993 [10]. He conducted a continuous temperature measurement of the septal mucosa during nasal breathing without giving information about the exact detection site. One major disadvantage of the used infrared thermometer is the long response time. Therefore, continuous breath synchronic temperatures measurements during the respiratory cycle could not be registered due to the long response time. Additionally, deeper intranasal parts were not accessible.

Another advantage of infrared thermograph camera systems is the two dimensional illustration of the temperature distribu-

tion within the entirely measured surface. Multiple measuring points are synchronously detected allowing a complete temperature mapping.

One well-known fact from numerical simulation is the inhomogeneous temperature distribution of the nasal mucosa during the respiratory cycle [9,11]. The temperature results within the nasal vestibule from our study support this aspect.

High spatial and temporal resolutions are further advantages. The response time of the applied thermocouple in previous studies [2,5-7] can achieve 2.5 to maximum 10 measurements per second. The applied infrared thermography cameras achieved a response time 50 (camera 1) und 60 (camera 2) measurements per second. Therefore, a continuous temperature measurement during the respiratory cycle is feasible. Analyzing the recorded infrared film, varying surface temperature profiles within the nasal vestibules could be observed. During inspiration, the nasal mucosa cools down. During expiration, the nasal mucosa is warmed again. Lindemann et al. were able to show that the degree of nasal mucosa cooling during inspiration, is correlated to nasal patency [12]. Therefore, infrared thermography camera systems could be used for contactless measurements of nasal airflow according to the relation between airflow and temperature changes.

Despite all advantages, the described method also presents relevant disadvantages. One limitation is the fact that only the temperature of the vestibular surface can be detected and measurements of the air temperature by thermal imaging are not possible yet.

The penetration depth into the nose is not really satisfactory, while only the anterior segment of the nose can be assessed. Perhaps the use of a nasal speculum could be helpful although it may alter nasal breathing and therefore affect results.

The answer to this problem would be an infrared thermography camera system connected to a nasal endoscope for in vivo intranasal temperature measurements within the entire nasal cavity for the first time allowing examinations of the posterior parts of the nose. This method would be limited by the physical characteristics of infrared radiation. Endoscopes used for clinical examinations in visible light filter the infrared radiation due to integrated light filter. At the moment, solutions with special endoscopes with an applicable outer diameter, e.g. with silicon light guides, cannot be easily implemented. An alternative solution for the infrared thermography could be a suitable infrared operation microscope.

CONCLUSION

Dynamic infrared thermography of the surface within the nasal vestibules is a useful measurement tool for the research and clinical investigation of intranasal heat exchange during respiration. Infrared thermograph camera systems allow a dynamic breath synchronic temperature mapping of the nasal surface with high local and temporal resolutions.

The study was able to prove the feasibility of the applied technical set-up. This set-up seems to be very promising for a wide range of further applications in rhinological research. The system will be developed gradually. In a second step, different sinonasal pathologies such as septal deviation, septal perforation and resection of the turbinates will be examined. Additionally, it will be used for the quantification of nasal airflow for the investigation of nasal breathing. Further studies will be carried out.

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