Endonasal Infrared Thermometry for the Diagnosis of Allergic Inflammation of the Nasal Mucosa in Patients with Bronchial Asthma

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Bronchial asthma (BA) is often associated with chronic inflammatory processes in the nasal mucosa; these processes give rise to allergic rhinitis, chronic rhinosinusitis, adenoiditis, and polypous rhinosinusitis. Due to their multiple symptoms, these diseases of the upper respiratory tract, especially allergic rhinitis, are often difficult to verify in patients with asthma.

The aim of the study was to evaluate the diagnostic potential of endonasal IR thermometry in BA patients suspected of allergic rhinitis.

Materials and Methods. Fifty children diagnosed with both BA and allergic rhinitis and 15 healthy children, matched by gender and age, participated in the study. The endonasal temperature determined with contactless IR thermometry was confronted with the symptoms of allergic rhinitis and sinusitis assessed with the TNSS and SNOT-20 questionnaires. The results were compared with the severity of nasal obstruction as determined through the anterior active rhinomanometry.

Results. The nasal temperature in patients with asthma and allergic rhinitis was 33.77 [33.37; 34.17]°C, which was significantly lower than that in the group of healthy children (34.98 [34.57; 35.39]°C; p=0.0006); the body temperature did not differ between the groups (36.55 [36.45; 36.65] and 36.58 [36.40; 36.76]°C, respectively; p=0.5). We found a negative correlation between the values of nasal temperature and the sinusitis symptom scores in patients with BA and allergic rhinitis (R=–0.32; p=0.02).

Conclusion. Patients with both BA and allergic rhinitis showed a decreased endonasal temperature in comparison with healthy children; the endonasal temperature can serve an indicator of allergic inflammation of the nasal mucosa.

Key words: endonasal infrared thermometry; bronchial asthma; allergic rhinitis.

Bronchial asthma (BA) is often associated with chronic inflammatory processes in the nasal mucosa; these processes give rise to allergic rhinitis (AR), chronic rhinosinusitis, adenoiditis, and polypous rhinosinusitis [1–3]. These comorbid conditions represent a serious challenge for medical professionals and have a negative impact on the quality of life of patients with asthma [3]. The diseases, especially AR, are difficult

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to verify in patients with asthma because of their multi-symptomatic and multi-factorial pathogenesis that stems from chronic inflammation of the nasal mucosa [4]. The similar diagnostic problems arise in patients with chronic obstructive diseases of the respiratory tract, which emphasize the universality of this problem [5].

Allergic rhinitis (ICD-10: J30) is an inflammatory disease manifested by a number of symptoms: running nose with nasal congestion, sneezing, itching, rhinorrhea, and edematous nasal mucosa. Its pathogenesis includes the IgE-mediated inflammation of the nasal mucosa, caused by the cause-significant allergens in sensitive patients [6].

In clinical practice, the diagnosis of AR is based on a combination of the characteristic clinical symptoms (sneezing, itching, rhinorrhea, nasal congestion) and the atopic syndrome; the latter is diagnosed by a characteristic allergic anamnesis and positive skin tests with aeroallergens, and/or detection in the serum of specific immunoglobulin E (IgE) antibodies to respiratory allergens. It is known that the manifestations of AR can be associated with the cellular composition of the mucus in the nasal cavity: in AR, 30% of cases show eosinophilia in the nasal secretion [7]. In addition, other biomarkers of the allergic process, including IgE and interleukins 4, 5, 13, tend to increase in patients with AR [8–10].

According to recent reports, there is a morphological and functional unity of the mucosa in the nasal cavity and the paranasal sinuses; therefore, the mucous membrane of the paranasal sinuses is involved in the inflammatory process including that of allergic genesis. Thus, the term “rhinosinusitis” sounds fully legitimate and necessitates a combined approach to inflammatory diseases of the nasal cavity and paranasal sinuses of any genesis [11–13].

The IgE-mediated inflammation of the nasal mucosa located around the ostiomeatal complex interferes with the mucus drainage from the paranasal sinuses [14]. Inflammatory edema of the mucosa and stagnant secretion disrupt the mucociliary clearance and nasal ventilation; the above changes facilitate a bacterial growth in the sinuses. In addition, the recent publications have clearly demonstrated that an inflammatory response to a nasal allergen develops not only in the nasal mucosa but in the paranasal sinuses as well [15, 16].

It was proposed that the airway temperature could serve a marker of mucosal inflammation and remodeling in patients with allergic and other inflammatory diseases of the respiratory mucosa, but so far only few studies addressed this issue [11–13]. The problem is complicated by the findings that the nasal temperature values may vary even in healthy individuals [12, 13].

At present, contact and non-contact thermometry methods are used to measure temperature. In the contact thermometry, temperature in the nasal cavity is measured by directly touching the mucosa with a thermo-sensor. This direct approach is not free from drawbacks as recently shown by Bailey et al. [12]: sometimes sensors irritate the mucosa, which can change the thermometer readings, make them dependent on the time of physical contact and introduce an uncertainty into the relation between the nasal patency and mucosal temperature. The authors conclude that in future research, preference should be given to the development of contactless thermometry to avoid mucosa irritation [12]. Among these methods, infrared (IR) thermometry is considered the most accessible one.

The aim of the study was to evaluate the relations between the nasal cavity temperature, the nasal clinical symptoms and the results of the anterior active rhinomanometry in patients with atopic bronchial asthma and allergic rhinitis. The nasal temperature was measured using infrared thermometry in the anterior end of the inferior nasal concha.

Materials and Methods. We examined a total of 50 patients (35 boys and 15 girls) aged from 2 to 17 years, earlier diagnosed with atopic BA associated with AR and followed up in Children’s Clinical Hospital No.1, Nizhny Novgorod, Russia. The study was conducted according to the Helsinki Declaration adopted in June 1964 (Helsinki, Finland) and revised in October 2000 (Edinburgh, Scotland) and approved by the Ethics Committee of the Nizhny Novgorod State Medical University. Informed consents were obtained from the patients between 15 and 17 years old and from the parents of patients under the age of 15, according to the Federal Law “Fundamentals of the Legislation of the Russian Federation on the Protection of Health of Citizens” of July 22, 1993, No.5487-1.

The diagnoses of BA and AR were verified in accordance with the internally and internationally accepted medical recommendations [14, 15]. All children under study had the symptomatic complex typical for BA combined with AR. The documented evidence included: a family history associated with atopy (asthma, AR, conjunctivitis, atopic dermatitis, urticaria), highly positive skin tests or the presence of immunoglobulins (IgE) specific for at least one of the most common aeroallergens in the Volga-Vyatka region of the Russian Federation.

All patients received treatment adjusted to the course and severity of the disease. The main exclusion criteria in this study were the presence of fever and/or symptoms of bacterial infection in the upper respiratory tract, including mucopurulent secretion in the nasal cavity.

All patients underwent comprehensive physical and ENT examinations that included a routine ENT examination, rhinovideo endoscopy (if indicated), rhinomanometry, a nasal mucosa culture test, cytological microscopy of nasal secretion, and an assessment of nasal symptoms using the Sino-Nasal Outcome Test-20 (SNOT-20) [16] and Total Nasal Symptom Score (TNSS) [17].

Examination of the upper respiratory tract included: 1) measurement of the body temperature and determination of the endonasal temperature using IR thermometry; 2) anterior active rhinomanometry; 3) visual ENT examination and clinical assessment. This multi-parametric approach allowed us to reduce the impact of errors associated with mono-parametric measurements.

The quantitative assessment of BA status was carried out using the Asthma Control Questionnaire-5 (ACQ-5) [18]. With the ACQ-5 score below 0.75, BA was considered fully controlled, with the ACQ-5 scores from 0.75 to 1.5 — partially controlled, and the score above 1.5 indicated uncontrolled BA [18, 19].

Determination of the endonasal temperature. The temperature of the nasal mucosa was determined with an infrared electronic thermometer WF-1000 (B.Well, England). The measurements were carried out after a 10 min rest in the sitting position. Patients were asked to maintain normal nasal breathing during the 10 s period of data collection. The temperature and the relative humidity of the ambient air were stable: 23±1°C and 40–50%. To measure the endonasal temperature an infrared sensor was placed on the nasal vestibule and orientated toward the anterior end of the inferior nasal concha; the measurements were performed in the exhalation phase only, repeated three times in each half of the nose, and the mean values were used for statistical analysis. The body temperature was measured in the ear canal using the same thermometer. The study included patients whose body temperature did not exceed 36.9°C and was not below 36.1°C.

Physical principles of non-contact IR thermometry. The physical basis of IR thermometry is the measurement of IR radiation in a given wavelength range. The power radiated from a unit surface over the entire range of wavelengths is related to the object temperature according to the Stefan–Boltzmann law:

$$P=\alpha\sigma T^4.$$

Here P is the radiation power per unit surface over the entire wavelength range, T is the absolute temperature, σ is the Stefan–Boltzmann constant, and α is the object's absorption capacity. If the absorption capacity does not depend on the wavelength and α=1, the object is called "the absolutely black body"; for 0<α<1 the object is called "the gray body". At the far IR wavelengths, most biological tissues have α≈0.95, which is close to the gray body.

The radiation power can be measured in various ways; today, semiconductor sensors that provide an analytical signal in the form of an electrical current are most commonly used. This approach is termed the contactless IR radiation thermometry. Its advantages are non-invasiveness, ease of use, time- and cost-saving procedure. This method has several features that one should keep in mind when taking measurements. First, the absorption capacities of various body tissues are not identical and they can change with a change in body's condition. Secondly, the readings are sensitive to ambient temperature because the background IR radiation increases the signal. Thirdly, in reality the sensor detects radiation not from a unit surface, but rather from a conical space in front of the sensor; due to that the size of the emitting "object" depends on the distance from the sensor to the tissue. Moreover, at a long distance, the device can detect radiation not only from the tissue but also from the background. Therefore, when performing measurements one must remember that a direct comparison of readings is valid only for similar tissues probed with similar measurement procedures. The following rules are recommended to be observed:

during the measurements, the ambient temperature must be kept constant if special compensation schemes are not provided in the device;

the sensor must be always situated at the same distance from the tissue; this distance should encompass the area of interest ("measurement spots") but should not involve adjacent areas.

Assessment of patency of the upper respiratory tract. The nasal respiratory function was assessed with the anterior active rhinomanometry using a Rhino 31 instrument (Atmos, Germany) in accordance with the standard international recommendations [20]. The system measured the volume of respiratory flow passing through the right and left half of the nose, the total volumetric flow, the resistance to flow in each of the nose halves, and the total nasal resistance. The nose resistance was automatically calculated at external pressures of 75, 150 and 300 Pa/cm^3/s. The measurements were carried out when the subject was in the sitting position; one nostril was completely blocked with a foam rubber roller. The patient was asked to stay calm and breathe uniformly through a silicone mask with his/her mouth closed. The results were displayed (in real time) in the form of a rhinogram, which was then processed and stored in the computer memory.

Studies of external respiration. Spirographic studies were performed using a MasterScreen Pneumo spirometer (Jaeger, Germany) in accordance with the existing international guidance [21]. The parameters of external respiration were evaluated and compared with the normal values considering the age, height, and sex of the child [19].

Statistical analysis. The data are presented as the median values Me [Q1; Q3]. The relationship between the endonasal temperature and the TNSS/SNOT-20 test results were processed using linear mathematical models; the data were compared using the unpaired t-test, ANOVA (F), and the Wilcoxon (W) or Kruskal–Wallis test (KWT) criteria. The difference was considered significant at $p<0.05$. Statistical analysis was carried out using StatGraphics 9.1 for Windows.

Results. The median value of the ACQ-5 scores (the BA control level) for all BA patients participated in the

study was 1.14 [1.03; 1.62]. Among them, in 23 children the scores did not exceed 0.75 (i.e., the disease was under control), in 14 children the scores varied within 0.75–1.5, and in 13 patients the ACQ-5 scores were greater than 1.5 points (uncontrolled BA).

We found a positive correlation between the ACQ-5 scores (indicating the BA control level) and the TNSS score (indicating the severity of AR symptoms), R=0.49; p=0.0004 (Table 1). A lower level correlation was found between the ACQ-5 scores and the SNOT-20 scores (R=0.31; p=0.03); the SNOT-20 test evaluates the condition of paranasal sinuses. These results can be interpreted as that in children with atopic BA, the symptoms of BA strongly correlate with the symptoms of AR, and to a lesser extent with the symptoms of sinusitis. In general, the obtained correlations support the concept of "single airways — single disease" with respect to the comorbidity of atopic BA and AR [22].

As the level of BA control decreases, the symptoms of AR progressively increase, which is manifested in the increase in the TNSS scores (Table 2). The differences are statistically significant, p=0.002. The sinusitis severity rates in patients with either a full or partial control of BA are close to each other; the severity, however, rises in children with uncontrolled BA, which confirms the opinion that sinusitis complicates achieving control over BA [23].

With the anterior active rhinomanometry, the total volumetric flow rate (VFR, cm^3/s) and the total nasal resistance (NR, $Pa/cm^3/s$) were determined in all children (see the Figure). According to the obtained results, children with atopic BA had lower VFR values (p=0.0001) and higher NR values (p=0.037) than children in the control group.

The nasal temperature in the control group was 34.98 [34.57; 35.39]°C, which was significantly higher than that in patients with BA, i.e., 33.77 [33.37; 34.17]°C; p=0.0006 (Table 3), and comparable to the results obtained by Peroni (33.9±0.7)°C in patients with AR [11]. The values of endonasal temperature in healthy subjects, obtained in our study, are comparable with those reported by Bailey et al. [12].

We have found that the endonasal temperature in patients with BA tends to decrease as the symptoms of AR increase, and especially the symptoms that indicate the involvement of paranasal sinuses. This notion is

Table 1

Correlations between the indices of bronchial asthma control (ACQ-5 scores) and the nasal symptoms (TNSS and SNOT-20 scores) in patients with bronchial asthma

Nasal symptom	Correlation formula	Correlation coefficient R	p
SNOT-20	Y=0.50+0.04 x	0.31	0.03
TNSS	Y=0.18+0.20 x	0.49	0.0004

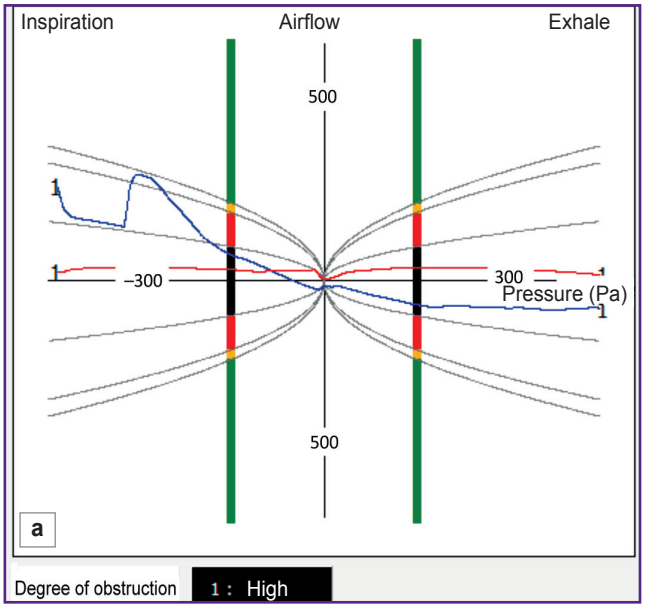
Here: Y — ACQ-5 score; x — either TNSS score or SNOT-20 score.

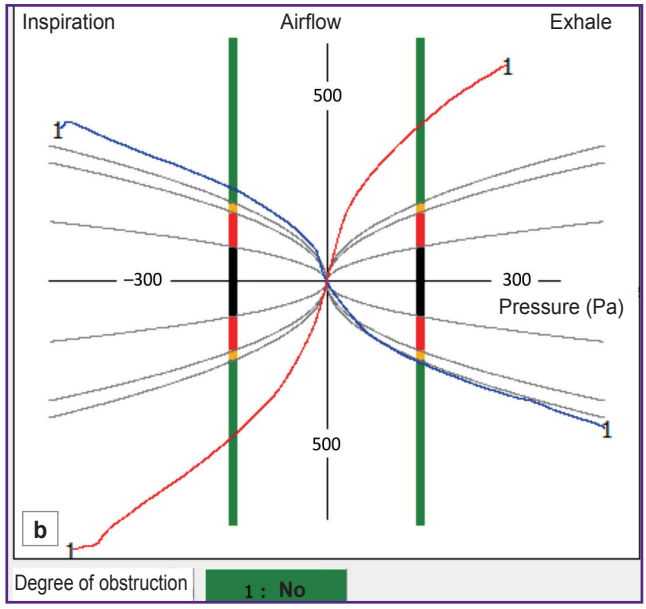
Table 2

The TNSS and SNOT-20 scores, the anterior rhinomanometry indices (VFR, NS), and the spirometry index (FEV1) in patients with different levels of bronchial asthma control (assessed with the ACQ-5 test) (Me [Q1; Q3])

Parameters	ACQ-5 score			Statistical analysis
	<0.75 (n=23)	0.75<ACQ-5<1.5 (n=14)	>1.5 (n=13)	
Bronchial asthma control	Full	Partial	No control	F=14.03; p<0.0001
FEV1 (%)	104.2 [102.7; 105.7]	96.6 [94.1; 99.4]	81.2 [78.0; 84.3]	
VFR (cm^3/s)	627.2 [517.1; 737.2]	498.7 [269.6; 727.8]	341.9 [191.9; 491.8]	F=2.6; p=0.1 KWT=4.5; p=0.11
NR ($Pa/cm^3/s$)	0.29 [0.16; 0.42]	0.35 [0.17; 0.09]	0.61 [0.45; 0.78]	F=2.7; p=0.1 KWT=5.0; p=0.08
TNSS score	3.05 [2.29; 3.80]	4.77 [3.79; 5.75]	6.33 [5.31; 7.36]	F=7.03; p=0.002 KWT=10.66; p=0.005
SNOT-20 score	13.45 [10.60; 16.31]	13.54 [9.82; 17.26]	20.5 [16.72; 24.37]	F=2.48; p=0.095 KWT=5.77; p=0.056

Here: FEV1 — the forced expiration volume per 1 second (% of normal values); VFR — total volumetric flow rate; NR — total nasal resistance.





Anterior active rhinomanometry: depiction of the results (Rhino 31; Atmos, Germany):
the thin blue line — the total volumetric flow rate in the left half of the nose, *the thin red line* — the total volumetric flow rate in the right half of the nose; *on the left* — the inspiration phase, *on the right* — the exhalation phase; the vertical lines show the ranges of nasal patency: *the black section* — the total volumetric flow rate in the range from 0 to 200 cm^3/s that reflects a high degree of nasal obstruction; *the red section* — the total volumetric flow rate in the range from 200 to 400 cm^3/s that reflects a moderate degree of nasal obstruction; *the yellow section* — the total volumetric flow rate from 400 to 455 cm^3/s that reflects a low degree of nasal obstruction; *the green section* — the total volumetric flow rate >455 cm^3/s that reflects an absence of nasal obstruction;
(a) clinical example 1: patient S., 8 years old; the diagnosis: "atopic bronchial asthma, moderate, exacerbation (ASQ-5 score 4.6, uncontrolled asthma). All-the-year-round allergic rhinitis, persistent, moderately severe, exacerbation; the nasal septum is deviated to the left; second degree adenoid vegetation". The total volumetric flow rate, both on the left (*the blue thin line*) and on the right (*the red thin line*), fall within the range from 0 to 200 cm^3/s, which indicates a high degree of nasal obstruction in this patient. He also displayed the following results: TNSS score 8; SNOT-20 score 21; nasal temperature 33.4°C; volumetric flow rate 108 cm^3/s; nasal resistance 1.39 $Pa/cm^3/s$;
(b) clinical example 2: patient A., 4 years old; the diagnosis: "atopic bronchial asthma with a mild intermittent course, remission (ASQ-5 score 0, full asthma control). All-year-round allergic rhinitis, intermittent, mild course, remission; second degree adenoid vegetation". The total volumetric flow rate both on the left (*the blue thin line*) and on the right (*the red thin line*), fall within the range of >455 cm^3/s, which indicates the absence of nasal obstruction in this patient. He also displayed the following results: TNSS score 1; SNOT-20 score 7; nasal temperature 35.6°C; volumetric flow rate 592 cm^3/s; nasal resistance 0.25 $Pa/cm^3/s$

Table 3

Comparison of nasal temperatures in patients with bronchial asthma and children in the control group (M±m; Me [Q1; Q3])

Parameters	Healthy (n=15)	Bronchial asthma (n=50)	Statistical analysis
Age (y.o.)	9.8±4.2	8.7±3.9	
Sex (boys/girls)	11/4	35/15	
ACQ-5 score	0.00 [0.00; 0.00]	1.14 [1.03; 1.62]	
SNOT-20 score	1.6 [–1.1; 4.25]	16.1 [13.1; 19.1]	W=54; p<0.0001
TNSS score	0.4 [–0.2; 1.0]	4.5 [3.7; 5.3]	W=58; p<0.0001
VFR (cm^3/s)	961.7±37.7	463.4±222.5	F=28.8; p=0.0001
NR ($Pa/cm^3/s$)	0.15±0.01	0.41±0.27	F=5.20; p=0.037
Body temperature	36.58 [36.40; 36.76]	36.55 [36.45; 36.65]	W=238; p=0.5
Endonasal temperature	34.98 [34.57; 35.39]	33.77 [33.37; 34.17]	W=412; p=0.0006

Here: VFR — total volumetric flow rate; NR — total nasal resistance.

Table 4

Correlations between the nasal temperature (t, °C) and the indices of nasal symptoms (TNSS and SNOT-20 scores)

Parameters	Correlation coefficient R	Correlation formula	p
SNOT-20	–0.32	103.7–2t	0.02
TNSS	–0.17	17.0–0.37t	0.22

based on a negative correlation between the SNOT-20 scores and the nasal thermometry data: R=–0.32; p=0.02 (Table 4).

Discussion. The significant decrease in the nasal temperature in patients with a combination of BA and AR, found in this study, suggests that the allergic inflammation typical for AP differs from the classical inflammation; specifically it is not accompanied by an increase in temperature. This finding calls for a detailed study because this phenomenon can reflect the mechanisms related to allergic inflammation in general. Probably, there is a common pathophysiological mechanism of the allergic process that leads to a lower temperature in the nasal mucosa in patients with AR and BA and underlies the intolerance to non-steroidal anti-inflammatory drugs found in many of these patients [24]. In addition, further studies on this phenomenon can help understanding the pharmacological activities of anti-leukotriene drugs; those are pathophysiological antagonists of non-steroidal anti-inflammatory agents.

Nasal thermometry can also be considered as a tool of differential diagnosis of nasal inflammation phenotypes.

Other advantages of IR thermometry are its non-invasiveness and low cost. However until now, contactless thermometry has not yet become the optimal and universal method to measure the endonasal temperature. Its use is limited by the requirement to strictly maintain stable temperature and humidity of the ambient air, as well as the requirement to measure the nasal temperature only during the exhalation phase (to unify the measurements); those obstacles complicate the use of IR thermometry in medical practice.

Conclusion. According to IR thermometry, children with bronchial asthma combined with allergic rhinitis have a decreased endonasal temperature as compared with their healthy peers. This finding may reflect the specifics of allergic inflammation in the nasal mucosa of allergic rhinitis patients, which requires a detailed study on the mechanisms and phenotypes of inflammation. The use of contactless endonasal thermometry for the diagnosis of allergic rhinitis is clinically feasible; yet further adjustment of this method to clinical practice is needed.

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Conflicts of Interest. The authors declare they have no conflicts of interest to be reported.

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