Different Swelling Mechanisms in Nasal Septum (Kiesselbach Area) and Inferior Turbinate Responses to Histamine

An Optical Rhinometric Study

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Objective: To determine whether the inferior turbinate, which contains swelling bodies, and the nasal septum (Kiesselbach area), characterized by a dense arterial mesh, exhibit different swelling mechanisms in allergic nasal reactions.

Design: Two optical rhinometers were used to examine 11 patients in the clinic. Optical rhinometry is based on the transillumination of the nasal septum and inferior turbinate or the whole nose with monochromatic light. The instrument's wavelength can be adjusted to the absorption characteristics of reduced hemoglobin, oxygenated hemoglobin, and water.

Setting: Outpatient university otolaryngology clinic.

Patients: Eleven young, healthy, nonsmoking, nonpregnant subjects (6 men and 5 women), mean age, 32.4 years (age range, 27-37 years), with no history of exposure to toxic substances, allergies, or other significant diseases.

Interventions: Optic rhinometry evaluation during the course of nasal histamine administration.

Main Outcome Measures: Light extinction at various wavelengths.

Results: Following administration of histamine, in the nasal septum, the wavelength of 950 nm (edema) showed the strongest increase of light extinction; in the inferior turbinate, it was the wavelength of 786 nm (oxygenated hemoglobin). In the whole nose, the wavelength of 880 nm (edema plus hemoglobin) exhibited the largest increase of extinction.

Conclusions: Swelling of the nasal septum (Kiesselbach area) in nasal allergic reactions is caused mainly by edema, whereas swelling of the inferior turbinate is due mainly to an increase in volume of blood that is highly saturated with oxygen. Swelling of the whole nose is characterized by the combination of both, edema and increase in blood volume.


A leading symptom of an allergic nasal reaction is the swelling of nasal tissue. While this congestion is mainly due to swelling of the cavernous tissue of the inferior turbinate, other structures like the nasal septum are also involved in the allergic reaction. However, the vascular structure of the nasal septum and the inferior turbinate are different. In the inferior turbinate, swelling bodies can be found; in contrast, the nasal septum (Kiesselbach area) is characterized by a dense arterial mesh.

The vascular arrangement of the inferior turbinate has been examined by corrosion casts and electron microscopic and histologic studies. The main arteries run deep parallel to the turbinal bone. From there, arterioles run to the surface of the turbinate where they become a dense capillary network located around the superficial glands. Electron microscopy studies reveal that these capillaries are fenestrated toward the glands. From the capillaries, the blood runs into cavernous veins located in the proprial mucosal lamina. These veins are characterized by surrounding muscular bolsters, which may be most important for the contraction of nasal swell bodies. Also, arteriovenous anastomoses have been noted in the inferior turbinate and have been suggested to play a role in nasal swelling. The venous drainage of the swell bodies runs via veins located in close proximity to the periosteum.

In contrast to the swelling bodies, the anterior part of the nasal septum (Kiesselbach area) is characterized by a dense arterial network. Branches of the ethmoidal arteries, the sphenopalatine artery, maxillary artery, palatine artery, and labial ar-
tery have dense anastomoses in Kiesselbach area.11-14 Capillaries are fixed at the perichondrium of the septal cartilage.10 Venous swelling bodies are not present.

Because of their different anatomies, it can be hypothesized that the 2 different structures respond differently within the context of nasal allergic reactions. Therefore, the aim of this study was to investigate whether swelling mechanisms differ between the Kiesselbach area and the inferior turbinate.

METHODS

Optical rhinometry (ORM) was used to assess nasal congestion.15-17 This evaluative technique is related to near-infrared spectroscopy, which is widely used to measure changes in oxygen saturation of hemoglobin.16-22 The basic principle of ORM is the transillumination of the nose or its parts by light of different wavelengths. A light emitter is placed on one side of the nose, and a detector is placed on the contralateral side. The nose is transilluminated continuously. Light extinction by nasal tissue is monitored in real time. If there is swelling in the transilluminated tissue, the light extinction increases, and less light can be detected by the detector. It is known from pulse oximetry and other optical diagnostic methods that light in the red and near-infrared wavelengths range (600-1000 nm) can penetrate soft tissue to depths of a few centimeters. As the light is scattered within the tissue, it travels also through tissue regions that are not directly aligned with the geometric source-detector axis.

Only few chromophores in the tissue absorb red and near-infrared light—predominantly hemoglobin, melanin, and water.23 Since endonasal swelling is characterized by an increase in blood volume and interstitial water (edema), this volume change can be measured as an increase in the absorption of light.

For the present study, 2 ORMs were used. One ORM was devised for measurements at the nasal septum (Kiesselbach area). The light emitter was introduced into one nasal cavity, and the detector was placed in the contralateral nasal cavity (Figure 1A). Using a slightly modified approach, we also took measurements at the level of the inferior turbinate; for this purpose, the emitter was placed inside of the nasal cavity, and the detector was placed outside of the nose (Figure 1B). For mea-
measurements involving the entire nose, a second ORM was used, and emitter and detector were placed on the left and right bridge of the nose, respectively (Figure 1C).

Some adjustment was necessary to compensate for the use of different rhinometers inside and outside the nose. Commercially available emitters small enough to be placed inside the nose are too weak to perform measurements from outside the nose. For ORM measurement inside the nose, 3 different wavelengths were used (686, 786, and 950 nm). For the measurement outside the nose, the wavelengths 660, 880, and 950 nm were used, to discriminate the absorption signals from hemoglobin (686 and 786 nm on the inside device and 660 and 880 nm on the outside ORM) and water (950 nm on both). Thus, both rhinometers measured similar, but not exactly the same, wavelengths.

The resulting differences in the measurements were corrected by mathematical algorithms (modified law of Lambert-Beer) using the absorption spectra of saturated oxygen, nonsaturated hemoglobin, and water. A basic assumption was that the concentration of chromophores not contained in the blood (e.g., melanin) would remain relatively constant during nasal congestion. The selected wavelengths are shown in Figure 2 along with a typical extinction spectrum of soft tissue and the spectral absorption coefficients of the tissue chromophores of interest. Discrimination between water and hemoglobin appears to be useful to distinguish between the hemodynamic response to an allergen and the development of interstitial edema. It is also possible to analyze hemoglobin oxygen saturation using the differential data at wavelengths of 686 and 786 nm (inside ORM) or 660 nm and 880 nm (outside ORM). In addition, it is possible to calculate the oxygen saturation in the surplus blood volume that produces the swelling by applying algorithms derived from pulse oximetry.16

In 11 young, healthy subjects (6 men and 5 women; age range, 27-37 years; mean age, 32.4 years), nasal swelling was induced by unilateral nasal administration of 0.14 mL of 2-mg/mL histamine. Subjects were nonsmokers, had no previous exposure to toxic substances, and had no allergies or other significant diseases. Pregnancy was excluded by a detailed and specific history. The study was approved by the ethics committee of the University of Dresden Medical School (study number EK204122001).

Experiments were performed on 3 separate days to allow for a complete recovery of the nasal tissue following administration of histamine. After the equipment was warmed up, optical sensor measurements were taken from the Kiesselbach locus, the inferior turbinate, or the whole nose. After an intranasal sensor was placed, its correct placement was endoscopically verified. For 2 minutes, the basal absorption of the nasal tissue was measured. Following this, 0.14 mL of histamine (2 mg/mL) was sprayed into 1 nostril, and the time course of light extinction was measured. Measurements were stopped after the extinction curve had reached a stable plateau; they were evaluated with regard to the change of light extinction of each of the 3 wavelengths. Using a suction catheter, we removed secretions carefully before and during the measurements.

RESULTS

MEASUREMENTS AT THE NASAL SEPTUM (KIESSELBACH AREA)

Following histamine administration, mean±SD light extinction was greatest at a wavelength of 950 nm (0.29±0.007 optical densities [OD]). At the wavelength of 686 nm, there was an increase of light extinction of 0.17±0.008 OD; at 786 nm, the increase was 0.19±0.006 OD. No significant difference (t = -0.82; P = .43) was found between the wavelengths of 686 and 786 nm. However, the wavelengths of 686 and 950 nm (t = -3.63; P < .001) and 786 and 950 nm (t = -7.80; P < .001) exhibited a significant difference (Figure 3).

MEASUREMENTS AT THE INFERIOR TURBINATE

The wavelength 786 nm exhibited the strongest increase in light extinction (0.18±0.008 OD). At 686 nm, the increase in light extinction was 0.09±0.005 OD; at 950 nm, it was 0.16±0.008 OD. The wavelengths of 686
and 786 nm differed significantly ($t_9 = -7.7; P < .001$). The difference between wavelengths of 686 and 950 nm was also significant ($t_9 = -6.56; P < .001$), as was that between the wavelengths 786 and 950 nm ($t_9 = 3.32; P = .01$) (Figure 4).

**MEASUREMENTS FOR THE WHOLE NOSE**

At 660 nm, an increase in light extinction of 0.27 ± 0.027 OD was found. The increase was 0.37 ± 0.027 OD at 880 nm and 0.34 ± 0.026 OD at 950 nm. There was a significant difference between 660 and 880 nm ($t_9 = 7.5; P < .001$) as well as between 660 and 950 nm ($t_9 = 6.5; P < .001$) and 880 and 950 nm ($t_9 = 3.6; P = .005$) (Figure 5).

Comparing the time course of the swelling after administration of histamine, there were no significant differences in the ORM results between the 3 conditions where measurements had been taken. Swelling started after $23 ± 16$ seconds, and maximum congestion was reached after $189 ± 93$ seconds. Results are summarized in Figure 5.

Figure 4. Optical rhinometry before and after administration of histamine, measured at the inferior turbinate. Approximately 10 seconds after administration, an increase of light absorption at all wavelengths was observed. The biggest increase was found at 786 nm, which might be interpreted as an inflow of oxygen-saturated hemoglobin into the inferior turbinate. OD indicates optical densities.

Figure 5. Optical rhinometry before and after administration of histamine at 120 seconds, measured across the whole nose. The greatest increase in extinction was seen at 880 and 950 nm (oxygen-saturated hemoglobin and water), which indicates an increase in oxygen-saturated hemoglobin. OD indicates optical densities.

Based on the differences in the vascular arrangement between the Kiesselbach area and the inferior turbinate, differences between these nasal areas in terms of their swelling during an allergic reaction (a reaction to administration of histamine) had been expected. The Kiesselbach area is characterized by a dense arterial mesh without swelling bodies.\textsuperscript{10-14} In contrast, the inferior turbinate is dominated by cavernous tissue.\textsuperscript{4-9} As an allergic reaction ultimately leads to the release of histamine from mast cells, in this study histamine was used to simulate nasal swelling caused by an allergic reaction. Nasal congestion was evaluated with the relatively new method of ORM, which has been proven to be useful for the monitoring of nasal allergen provocation tests. This method has a rather good correlation compared with rhinomanometry ($r = -0.74$). The correlation of ORM with the subjective impression of changes in nasal swelling ($r = -0.74$) is better than the correlation of rhinomanometry with the subjective impression of changes in nasal congestion ($r = -0.75$).\textsuperscript{24} With ORM, which is derived from near-infrared spectroscopy,\textsuperscript{18-22} real-time monitoring of changes in nasal swelling is possible as well as the evaluation of the physiologic background of the swelling.\textsuperscript{15-17}

Histamine provocation at the nasal septum (Kiesselbach area) leads to a stronger increase in light extinction at the wavelength of 950 nm (edema) at the Kiesselbach area of the nasal septum. At the level of the inferior turbinate, the increase in absorption at 786 nm (oxygen-saturated hemoglobin) was most significant. When measurements were performed over the whole nose, the increase in light extinction of 660 nm (nonsaturated hemoglobin) was less than 880 or 950 nm. Error bars indicate standard deviation. OD indicates optical densities.

Figure 6. Nasal histamine administration led to an increase of absorption at the wavelength of 950 nm (edema) at the Kiesselbach area of the nasal septum. At the level of the inferior turbinate, the increase in absorption at 786 nm (oxygen-saturated hemoglobin) was most significant. When measurements were performed over the whole nose, the increase in light extinction of 660 nm (nonsaturated hemoglobin) was less than 880 or 950 nm. Error bars indicate standard deviation. OD indicates optical densities.

**COMMENT**

Histamine provocation at the nasal septum (Kiesselbach area) leads to a stronger increase in light extinction at the wavelength of 950 nm (edema) compared with 686 or 786 nm. This can be interpreted as an increase of water in the measured area. As secretions had been removed...
carefully with a suction catheter during the measurements, the increase of water can be explained as edema. Accordingly, these data can be interpreted to indicate that swelling in the Kiesselbach following histamine provocation (or as an allergic reaction) is caused mainly by edema, and that blood influx plays a less important role. The increased extinction at wavelengths of 686 and 786 nm with a missing difference between the 2 wavelengths can be interpreted as an increase in blood volume without a change in oxygen saturation.

At the level of the inferior turbinate, histamine provocation led to a stronger increase in light extinction at the wavelength 786 nm compared with 950 nm and 686 nm. This can be interpreted to indicate increasing blood supply to the inferior turbinate following histamine provocation. This finding is related to the anatomic observations of large swelling bodies in this nasal area. Using algorithms derived from pulse oximetry, we can determine that the oxygen saturation of the surplus blood volume in the swelling bodies was 94%. This relatively high oxygen saturation in the “venous” swelling bodies can be explained by the lack of oxygen-using structures in the tissue of the inferior turbinate.

It must be discussed why the increase in extinction after nasal histamine provocation was lower at the inferior turbinate than at the nasal septum. This finding was unexpected, since the swelling bodies of the inferior turbinate should lead to an increase in light extinction. However, when measuring changes in the state of congestion at the nasal septum, we place the optical sensor at the upper end of the inferior turbinate. Thus, there is enough space between sensor and nasal septum to allow for an unrestricted swelling. In contrast, for measurements of the inferior turbinate, the optical sensor is placed medially to the inferior turbinate, which allows for less space for the swelling process.

From the results for whole nose measurements, it can be stated that there was a significant difference between the wavelengths of 880 and 950 nm and between 880 and 680 nm. This indicates that swelling of the entirety of the intranasal tissue appears to be mostly related to an increase of blood, while an increase of the interstitial edema plays a lesser role.

In conclusion, the nasal septum (Kiesselbach area) and inferior turbinate exhibit different mechanisms of swelling in response to histamine administration. The swelling of the Kiesselbach area is mainly due to interstitial edema, while swelling of the inferior turbinate is mainly characterized by an increase in blood volume with a high oxygen saturation. These findings might be important in diagnosing allergies or changes in microcirculation. In diagnosing allergies, the measurement should be done at the inferior turbinate to detect the predominating increase of blood volume following a positive allergen reaction. Changes in microcirculation that finally lead to the development of an interstitial edema might be detected by measuring the nasal septum (Kiesselbach area). In the future, this technique might be a noninvasive method for the monitoring disorders of microcirculation.

Submitted for Publication: April 21, 2005; final revision received August 16, 2005; accepted September 7, 2005.