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Diagnostic value of acoustic rhinometry: Patients with allergic and vasomotor rhinitis compared with normal controls

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SUMMARY

By means of the acoustic reflection technique, termed acoustic rhinometry, cross-sectional areas along the whole upper airway can be measured by an acoustic click. This paper describes the normal values obtained from 134 probands.

The normal curve shows the minimal cross-sectional area (I-notch) to be located at the isthmus nasi. The second narrowest segment of the nasal cavity is located at the head of the inferior concha (C-notch).

In patients with turbinate hypertrophy due to allergic or vasomotor rhinitis the minimal cross-sectional area is sited at the head of the inferior turbinate.

Furthermore, acoustic rhinometry allows exact measurements of size and location of the congested mucosa following challenge with allergens in patients affected with allergic rhinitis.

After anterior turbinoplasty of patients with turbinate hypertrophy improved nasal breathing was associated with an enlargement of the cross-sectional areas at the head of the anterior inferior turbinate.

Acoustic rhinometry not only enables to distinguish the various deviations of the nasal structures from normal (valve stenosis, septal deviation, turbinate hypertrophy, tumour masses) concerning their location and size, but also allows to demonstrate exactly the efficacy of rhinosurgical techniques.

INTRODUCTION

Acoustic rhinometry, based on Jackson's algorithm (1977) to calculate area-distance function of airway in the lung, was introduced as a new objective method to assess the geometry of the nasal cavity by Hilberg et al. (1989). They demonstrated its usefulness in ten normal subjects and in two patients with well defined afflictions of the nasal cavity.

Most recently (Grymer et al., 1989) the authors reported of the diagnostic possibilities of acoustic rhinometry in some patients with septal deviations before and after septoplasty.
We will show the value of this method in evaluating patients with allergic and vasomotor rhinitis.
Furthermore, we demonstrate that acoustic rhinometry is a useful method to assess the efficacy of anterior turbinoplasty. By this, it is shown that surgical treatment can reduce nasal obstruction in cases resistant to medical treatment.

METHODS

Subjects

134 Caucasian subjects, 74 men and 60 women, aged 21 to 60 years, served as normal controls, defined by the following inclusion criteria: no nasal history, no midfacial abnormalities, no significant septal deformities and no turbinate hypertrophy. 121 patients with allergic or vasomotor rhinitis, 54 men, 76 women, aged 18 to 61 years, with a mainly straight septum were examined. All 255 subjects were assessed by the same otolaryngologist.

Definition

Vasomotor rhinitis in our patients is defined as chronic nasal obstruction and nasal hypersecretion, with hypertrophy of both inferior turbinates and negative reactions to the allergic tests. Patients with positive reactions to allergic tests were taken as representative of the allergic group.

Equipment

For acoustic rhinometry, we used the following equipment (Figure 1) according to Hilberg et al. (1989). It consists of a computer (IBM^R-AT 386 compatible) with analog-to-digital converter (Metrabyte, DASH-16), a spark-generator, a wave tube made by bakelite (1.5 cm ID, 90 cm length) and piezo-microphone with a 20 dB amplifier and a 10 kHz low-pass filter.
Apart from Hilberg et al. (1989) we use 12 different polyphen nosepieces (inner-diameter 1.5 cm, length 7 cm) with a concave opening at the nostril measuring from 0.4 to 1.5 cm outer-diameter. Under visible control a tight fit of the nosepiece to the individual nostril without any deformation of the nasal lobule is achieved. The click is reflected by changes in local impedance resulting from changes in the cross-sectional areas of the nasal cavity. The analog signal from the microphone is amplified, filtered, and digitized at a sampling rate of 40 kHz. The data are converted to an area-distance function by software as described by Jackson et al. (1977), and visualized with area plotting on logarithmic scale in the video display.
Five to seven curves in each different state (before and after decongestion, right

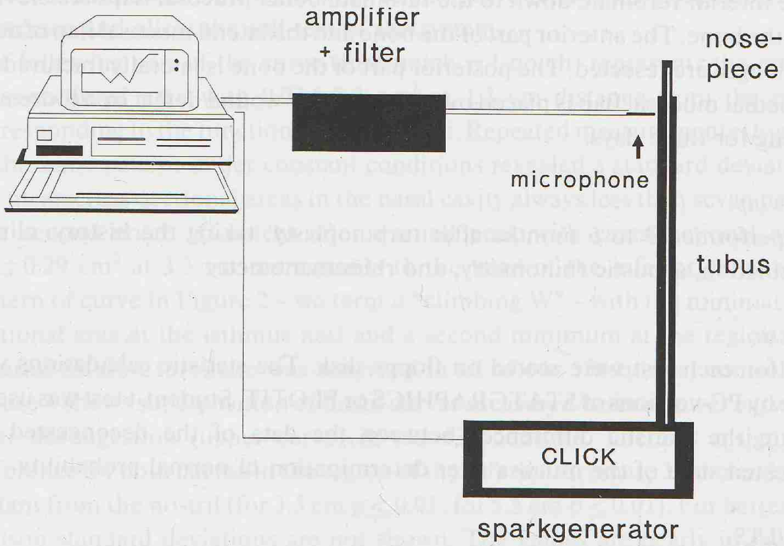

Figure 1. Apparatus for acoustic rhinometry. Wave tube is connected to nasal cavity by one of 12 different nosepieces according to the individual size of the nostril.

and left) were recorded. Superposition of different curves is used for evaluation and documentation.
Subsequently rhinomanometry was performed as active computerized anterior rhinomanometry (Rhinomanometer MP, EVG) according to the evaluation method described by ISCR (1985). Five to seven pairs of flow-pressure curves are recorded. Flow volume values measured by rhinomanometry are referred to 150 Pa.

Decongestion test
Patients are measured by acoustic rhinometry and rhinomanometry before and 15 minutes after decongestion with tramazoline 0.5%. This test was performed by spraying the solution into the inferior and middle nasal meatus.

Allergic test
All patients in the group of specific or nonspecific hyperactivity were examined with the help of history, by allergen skin tests, by nasal challenge (allergen solution is dropped with a needle on the head of the inferior turbinate), and/or by RAST.

Surgery
We use a method of anterior turbinoplasty according to Gray (1965). Under local or general anaesthesia a curved incision is made along the anterior inferior edge

of the inferior turbinate down to the turbinate bone. Mucosal flaps are elevated from the bone. The anterior part of the bone and the lateral mucosal flap of about 2 cm length are resected. The posterior part of the bone is laterally fractured and the medial mucosal flap is placed over the anterior wound defect by a loose nasal packing for three days.

Follow-up

It is performed 3 to 6 months after turbinoplasty, taking the history, clinical examination, acoustic rhinometry, and rhinomanometry.

Statistic

Data for each test were stored on floppy disk. The statistic calculations were made by PC-versions of STATGRAPHICS or PLOTIT. Student-t test was used to evalute the statistic differences between the data of the decongested and congested state of the mucosa after determination of normal probability.

RESULTS

Normal controls

The cross-sectional areas of the nasal cavity are obtained as a function of distance from the nostril. Figure 2 shows the mean curve of 134 normal controls with standard deviation. The range of standard deviations is mainly a result of the interindividual differences of the measurements.

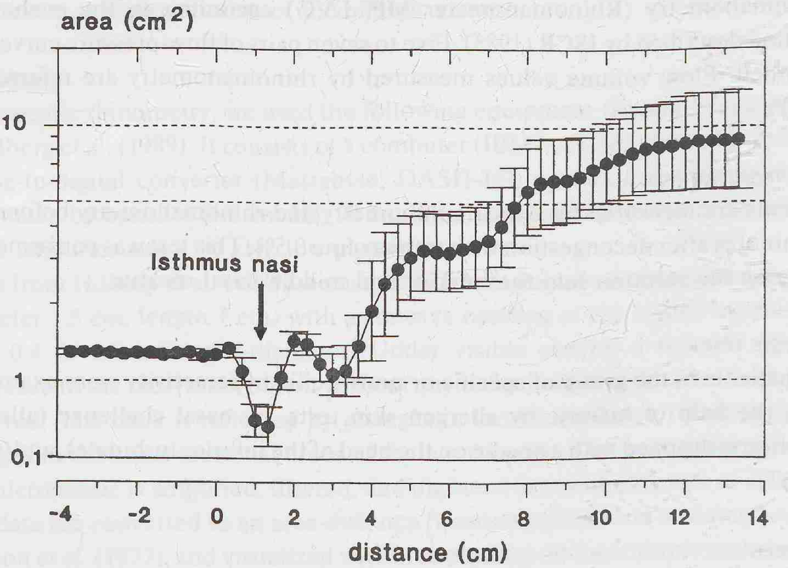

Figure 2. AREA-DISTANCE function obtained by acoustic rhinometry; mean curve and standard deviation of cross-sectional areas in normal controls [n=134].

The first centimeters (straight line) of the curve reflect the dimension of the nosepiece and allow the self-test of the system.
The following part of the curve (first notch = I-notch) represents the minimal cross-sectional area with 0.73 ± 0.2 cm^2 at 1.3 cm distance from the nostril, corresponding to the functional isthmus nasi. Repeated measurements (Figure 3) in the same patient under constant conditions revealed a standard deviation of the mean cross-sectional areas in the nasal cavity always less than seven percent.
The second notch (C-notch) after a small peak with cross-sectional area of 1.1 ± 0.29 cm^2 at 3.3 cm corresponds to the head of the inferior concha. This pattern of curve in Figure 2 – we term it "climbing W" – with the minimal cross-sectional area at the isthmus nasi and a second minimum at the region of the anterior inferior turbinate was observed in all of our 134 normal controls.
Figure 4 shows superposition of mean curves measured before (lower curve) and after decongestion (upper curve) in our 134 controls. There is a significant difference for both curves in the region of the inferior turbinate 3.5 cm and 5.5 cm distant from the nostril (for 3.5 cm $p \leq 0.01$; for 5.5 cm $p \leq 0.01$). For better comparison standard deviations are not shown. The values are nearly in the same range with respect to the congested and decongested state.
These two curves are identical at the isthmus nasi (valve region) reflecting the anatomical fact, that nasal mucosa cannot be found in the isthmus nasi.
The curves separate in the beginning of the anterior inferior turbinate, due to the congestive capacity of the nasal mucosa.
In all our normal controls, before and also after decongestion, the minimal cross-

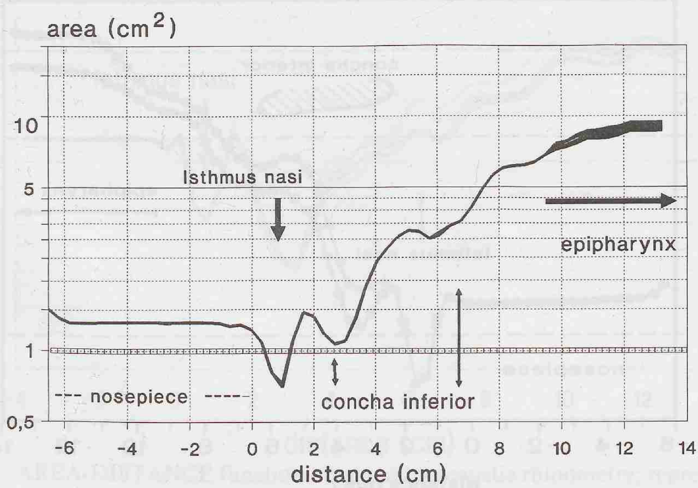

Figure 3. AREA-DISTANCE function obtained by acoustic rhinometry; superposition of six measurements within 12 seconds of one decongested nasal cavity.

Acoustic rhinometry demonstrates a minimal cross-sectional area of 0.31 cm^2 at 3.5 cm (Figure 6) from the nostril before challenge with house dust.
This stable condition for the cross-sectional areas in the nasal cavities corresponds with the patient's feeling, that nothing has changed in his nose.

Positive allergic reaction
In contrast to Figure 6, Figure 7 represents the positive response after intranasal challenge for a patient with allergy against house dust. The minimal cross-sectional area is increasingly reduced over the observation period of half an hour. Before the exposition with house dust, the minimal cross-sectional area was 0.4 cm^2 at 3.2 cm from the nostril in the region of the inferior turbinate ("descending W-pattern"). 15 minutes after challenge, the area is reduced to 0.3 cm^2 at 3.4 cm from the nostril. 30 minutes after challenge, this area is almost blocked with a cross-sectional area of 0.15 cm^2.
Similar data are confirmed by anterior rhinomanometry: 0 min: 216 ml s^{-1}; 15 min: 126 ml s^{-1}; 30 min: 82 ml s^{-1} at 150 Pa.
Note, that the reduction of the cross-sectional area is not limited to the head of inferior turbinate, where the allergen solution was dropped on, but also includes the areas behind this point.

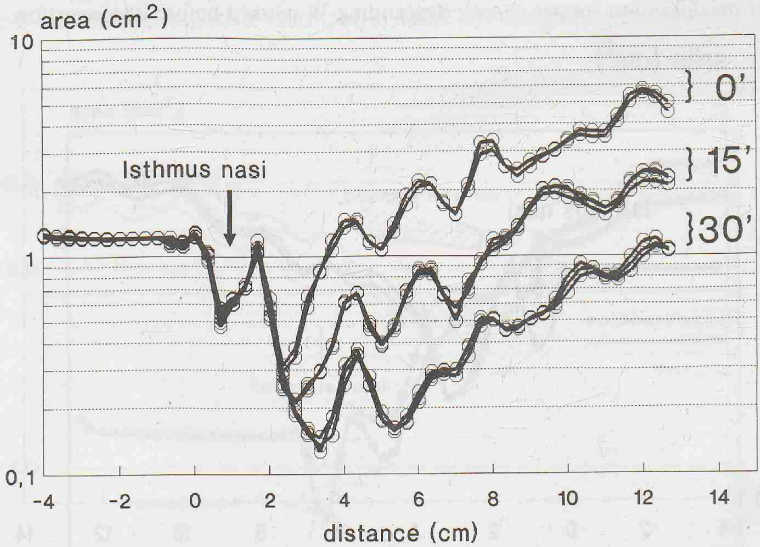

Figure 7. AREA-DISTANCE function obtained by acoustic rhinometry; representative for a remarkable response to a nasal challenge in a patient with turbinate hypertrophy: The curves before challenge, 15 and 30 minutes after challenge show an impressive narrowing of cross-sectional areas corresponding to rhinomanometry: before 216 mls^{-1}, 15 minutes 126 mls^{-1} and 30 minutes 82 mls^{-1} at 150 Pa.

Vasomotor rhinitis
A paradoxical response was recorded in a patient with vasomotor rhinitis (Figure 8). This patient initially reacted with a widening of the cross-sectional area in the C-notch after the challenge with an allergen solution, instead of a reduction as observed in Figure 7. Before the testing a minimal cross-sectional area of 0.53 cm^2 at 3.2 cm was found, corresponding to the head of inferior turbinate. 15 minutes after the allergen solution has been applied to the mucosa of the anterior inferior turbinate, the patient reported nasal hypersecretion and itching with normal nasal breathing. By acoustic rhinometry it could be shown that this secretion was paralleled by a localized widening of the cross-sectional area in the C-notch (0.9 cm^2 at 3.8 cm). A control measurement 30 minutes later indicated, that the condition of the nasal mucosa has returned to the status before (0.53 cm^2). This was paralleled by the patient's report, that the nasal secretion had ceased.

Acoustic rhinometry after turbinoplasty
Acoustic rhinometry was used to follow up the patients before and after turbinoplasty. As an example patient V.M. is shown before (Figure 5) and after (Figure 9) turbinoplasty of the right inferior turbinate. Comparing both figures, we see that the pre- and postoperative values of the cross-sectional areas at the isthmus nasi (0.45 cm^2) are identical. But in contrast to this, surgical treatment resulted in a

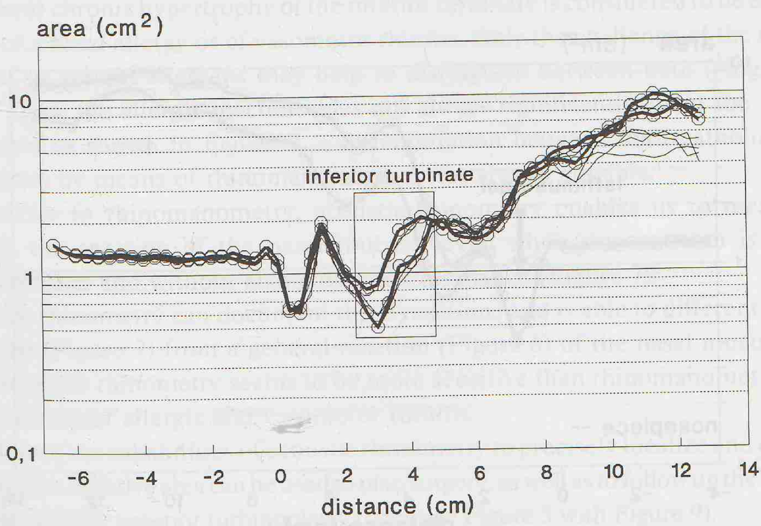

Figure 8. AREA-DISTANCE function obtained by acoustic rhinometry; representative for a paradoxical response in nasal challenge in a patient with turbinate hypertrophy: 15 minutes after application of allergen solution a strictly localized widening of cross-sectional areas at 3.8 cm from the nostril is registered, 30 minutes after application the same response as before application is measured.

widening of the region of the inferior anterior turbinate (C-notch): from 0.34 cm^2 preoperatively to 0.7 cm^2 postoperatively in the non-decongested state and from 0.7 cm^2 pre- to 1.0 cm^2 postoperatively in the decongested state.
Thus by acoustic rhinometry, we can show that reduction surgery of the anterior inferior turbinate has improved breathing conditions in this patient with values quite similar to those found in controls. The minimal cross-sectional area is situated at the isthmus nasi six months postoperatively (I-notch).

DISCUSSION

This study deals with the fascinating challenge in the diagnostic of nasal patency, introduced by acoustic rhinometry. We have used the method, originally described by Hilberg et al. (1989), to evaluate its clinical significance in patients with allergic and vasomotor rhinitis.
Since until now data on cross-sectional areas in a larger group of normal controls were not available, we have established these values along the upper airway in 134 subjects.
The minimal cross-sectional area was measured to be 0.73 cm^2 and was constantly located at the region of the nasal valve (I-notch).
This area favourably corresponds to the isthmus nasi, which has been previously reported by Legler (1967) and by Bachmann (1973, 1982), by means of impressions of the anterior nose to be 0.8 cm^2 in men and 0.71 cm^2 in women.

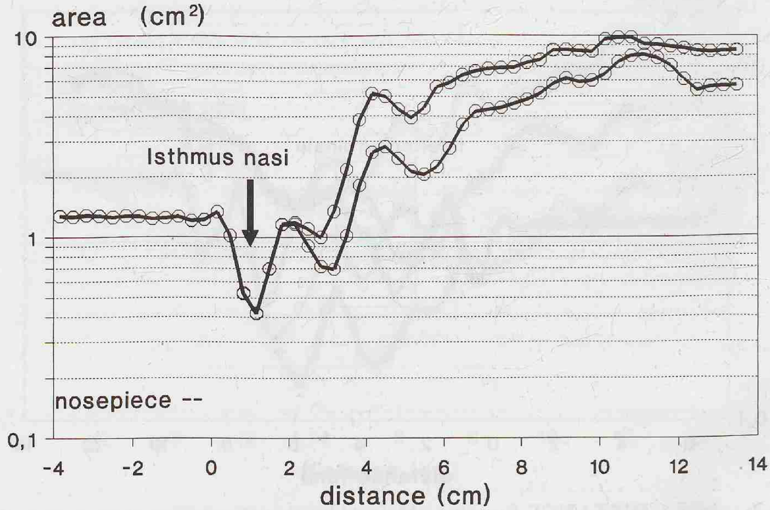

Figure 9. AREA-DISTANCE function obtained by acoustic rhinometry; patient with turbinate hypertrophy 6 months after reduction of the right anterior inferior turbinate: Cross-sectional areas at the isthmus nasi are identical to preoperative values (Figure 5), surgery effects a widening in the region of the anterior inferior turbinate.

Measuring the nasal resistance in normals by different methods, Masing (1967), Legler (1967), Fischer (1969), and Bachmann (1973, 1982), and most recently Haight and Cole (1983) showed that the most resistive segment is sited in the region between the valve and the head of inferior turbinate. Acoustic rhinometry allows a more detailed analysis of this most resistive segment.

In normal controls it contains two minimal cross-sectional areas, the I-notch at 1.3 cm and the C-notch at 3.6 cm from the nostril ("climbing W"-pattern). We found that in normal controls the first notch (I-notch) always represents the minimum of the cross-sectional areas of the whole nasal cavity.

In normal controls the minimal cross-sectional area of the C-notch is always larger then the minimal cross-sectional area of the I-notch.

This differs from pathological conditions: in patients with turbinate hypertrophy the minimum of the cross-sectional areas of the nasal cavity is located in the region of the anterior inferior turbinate (C-notch). The values of the I-notch remain unchanged compared with normal controls. Thus in our diagrams this rhinometric curve imposes as a "descending W" (Figures 5–8).

The additional reduction of cross-sectional areas of the C-notch in patients with turbinate hypertrophy explains the increase of the nasal resistance, which we could confirm by active anterior rhinomanometry in our patients.

By means of rhinomanometry Jones et al. (1987) found a higher nasal resistance in patients with turbinate hypertrophy compared with normal controls, too.

A bilateral chronic hypertrophy of the inferior turbinate is considered to be either a sign of a nasal allergy or of vasomotor rhinitis. Only the challenge of the nasal mucosa to certain allergens may help to distinguish between both (Änggård, 1988). Since the allergic reaction does not always significantly affect the nasal resistance as shown in Figure 7, a differentiation between both pathological conditions by means of rhinomanometry is not always possible.

In contrast to rhinomanometry, acoustic rhinometry enables us to measure directly the reaction of the nasal mucosa, even when this reaction is only circumscribed and without changing nasal resistance (Figure 7).

Acoustic rhinometry can document these reactions and is able to differentiate a localized (Figure 7) from a general reaction (Figure 6) of the nasal mucosa.

Thus acoustic rhinometry seems to be more sensitive than rhinomanometry for the diagnosis of allergic and vasomotor rhinitis.

In addition, the capabilities of acoustic rhinometry to precisely localize and quantify the most resistive area can be used to plan surgery, as well as to follow up the surgical treatment by anterior turbinoplasty (compare Figure 5 with Figure 9).

In another paper (in preparation) we will show that all findings and results presented here can be found not only in patients with a straight septum, but also in patients with septal deviations.

In conclusion acoustic rhinometry enables the exact measurement of the size and location of a nasal obstruction, thus providing the base to differentiate between valve stenosis, turbinate hypertrophy, septum deviation, polyps, or other masses in the nasal cavity.

REFERENCES

1. Änggård A. Specific and nonspecific nasal hyperreactivity. In: Passali D, Ed. Around the Nose. Firence: Conti Tipocolor, 1988; 45–54.
2. Bachmann W. Untersuchungen über Morphologie und Funktion des vorderen Nasenabschnittes. Habilitationsschrift, Heidelberg: 1973.
3. Bachmann W. Die Funktionsdiagnostik der behinderten Nasenatmung. Berlin, Heidelberg, New York: Springer Verlag, 1982.
4. Fischer R. Die Physik der Atemströmung in der Nase. Habilitationsschrift, Berlin: 1969.
5. Gray L. The deviated nasal septum. II Prevention and treatment. J Lar 1965; 79: 806–816.
6. Grymer LF, Hilberg O, Elbrondl O, Pedersen OF. Acoustic rhinometry: evaluation of the nasal cavity with septal deviations, before and after septoplasty. Laryngoscope 1989; 99: 1180–1187.
7. Haight JD, Cole JP. The site and function of the nasal valve. Laryngoscope 1983; 93: 49–55.
8. Hilberg O, Jackson AC, Swift DL, Pederson OF. Acoustic rhinometry: Evaluation of nasal cavity geometry by acoustic reflections. J Appl Physiol 1989; 66: 295–303.
9. International Standardization Commitee on Rhinology. Chairman: Clement PAR, ENT Department, AZ-VUB, Laarbeeklaan 101, 1090 Brussels, Belgium, 1985.
10. Jackson AC, Butler JB, Millet EJ, Hoppin FG jr, Dawson SV. Airway geometry by analysis of acoustic pulse response measurements. J Appl Physiol 1977; 48: 523–536.
11. Jones AS, Lancer JM. Does submucosal diathermy to the inferior turbinates reduce nasal resistance to airflow in the long term. J Lar Otol 1987; 101: 448–451.
12. Legler U. Beitrag zur Morphologie, Physiologie und Klinik des Vestibulum nasi vermittels eines neuzeitlichen Abdruckverfahrens. Z Lar Rhinol Otol 1967; 46: 482–487.
13. Masing H. Experimentelle Untersuchungen über die Strömung im Nasenmodell. Arch Klin Exp Ohren Nasen Kehlkopfheilkd 1967; 189: 59–70.

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