
CME review article

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Acoustic rhinometry in the practice of allergy

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Objective: To provide a comprehensive practical overview of the use of acoustic rhinometry in the practice of allergy.

Data Sources: An all-inclusive PubMed search was conducted for articles on acoustic rhinometry that were published in peer-reviewed journals, between 1989 and 2006, using the keywords *acoustic rhinometry*, *allergic rhinitis*, and *nasal provocation testing*.

Study Selection: The expert opinion of the authors was used to select studies for inclusion in this review.

Results: Acoustic rhinometry is a sound-based technique used to measure nasal cavity area and volume. It has been validated by comparison to measurements with computed tomography and magnetic resonance imaging. Acoustic rhinometry requires minimal patient cooperation and may be used in adults, children, and infants. It is used by medical practitioners to diagnose and evaluate therapeutic responses in conditions such as rhinitis and to measure nasal dimensions during allergen provocation testing. Acoustic rhinometry also provides a visual reflection of the nasal response to therapy, which may be useful in increasing compliance to prescribed medications.

Conclusions: Acoustic rhinometry is a safe, noninvasive, objective, and validated measure of nasal obstruction that appears to be of practical use in the diagnosis and management of inflammatory diseases of the upper airways.

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INTRODUCTION

Allergic rhinitis is a common atopic disease.¹ In 2003, the US Department of Health and Human Services reported that the annual medical cost for allergic rhinitis was approximately \$7.7 billion. Allergic rhinitis may also contribute to the exacerbation of asthma and to sinusitis, which further increases the national financial burden.² Nasal obstruction is a key feature of rhinitis and is often defined as the discomfort experienced during breathing due to insufficient nasal airflow secondary to decreased nasal patency.³ This obstruction may be evaluated subjectively by symptom scoring and visual analog scales or objectively by measuring resistance to nasal airflow with

anterior and posterior rhinomanometry, measuring light extinction in nasal tissues by optical rhinometry, quantifying nasal airflow with a peak inspiratory or peak expiratory flow meter, or measuring the nasal cavity area and volume with acoustic rhinometry. Studies have shown that the patient's perception of nasal obstruction does not correlate with the actual compromise in nasal airflow.⁴ As a result, objective measure of obstruction with the use of acoustic rhinometry provides a significant benefit in the evaluation of rhinitis. In this setting, acoustic rhinometry has become an important technique because it is also noninvasive and has been validated to measure nasal cavity area and volume.

This article aims to provide a comprehensive practical overview of the use of acoustic rhinometry in the practice of allergy. An all-inclusive PubMed search was conducted for articles on acoustic rhinometry that were published, between 1989 and 2006, in peer-reviewed journals, using the key-

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words *acoustic rhinometry*, *allergic rhinitis*, and *nasal provocation testing*. The expert opinion of the authors was used to select studies for inclusion in this review.

MEASUREMENTS

Acoustic rhinometry measures cross-sectional area (CSA) and volume by acoustic reflections at various distances from the nasal inlet. A sound wave in an audible frequency range is generated by a microprocessor and transmitted through a fixed dimension tube. The computer software makes a comparison of the reflected sound impulse with the incident wave (initial sound impulse). A waveform is then graphically generated that indicates the CSA of the nasal cavity as a function of distance into the nasal cavity. This graphically generated waveform depicts valleys or notches that are created by deflections of the sound impulses as they make contact with nasal mucosal tissue. The first 3 “notches” in the graph after the nosepiece are termed CSA1, CSA2, and CSA3. Anatomically, CSA1 is considered to correspond to the nasal valve and is 0.5 to 1.0 cm from the nasal inlet, CSA2 corresponds to the anterior half of the inferior turbinate and is 2.0 to 4.0 cm from the nasal inlet, and CSA3 corresponds to the middle portion of the middle turbinate and is 4.0 to 6.0 cm from the nasal inlet.^{5–7} The minimal CSA corresponds to the narrowest CSA of the nasal cavity and often reflects the location of the greatest mucosal swelling; it varies in distance from the nasal inlet. Figure 1 presents the nasal cavity anatomy and the corresponding graphic representation, termed the rhinogram, that displays these cross-sectional locations.

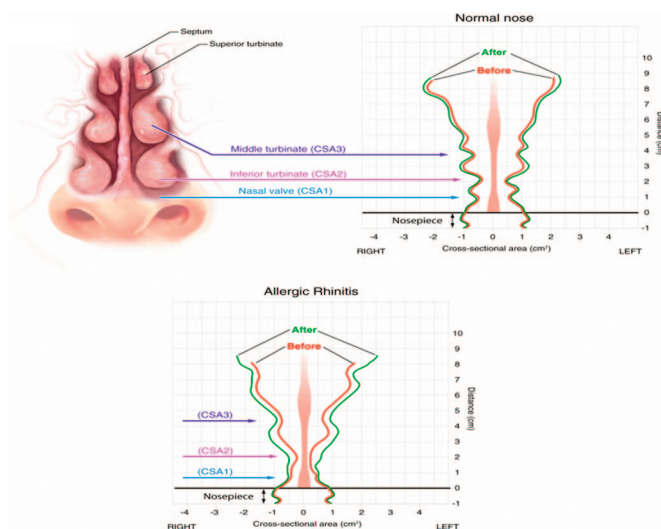


Figure 1. The anatomy of the nasal cavity and corresponding rhinogram. Top left, Schematic diagram of the normal nose illustrating the nasal turbinates and the nasal septum. Top right, Predecongestant and postdecongestant rhinogram of a healthy person. No significant difference is seen in postdecongestant cross-sectional areas 1, 2, and 3. Bottom, Predecongestant and postdecongestant rhinogram of a person with allergic rhinitis. Measurable increase is seen in postdecongestant cross-sectional areas 2 and 3.

Studies have reported that CSAs can vary, depending on the ethnicity, age, and height of patients.⁸ Variations in turbinate hypertrophy as seen with nasal mucosa inflammation may locate the minimal CSA to the nasal valve, inferior turbinate, or middle turbinate.⁹ In allergic or vasomotor rhinitis, the minimal CSA tends to shift to the head of the inferior turbinate.¹⁰

Generally, 3 sequential measurements are taken of each nasal cavity from which a mean is calculated. This procedure is often followed by administration of an intranasal decongestant and subsequent postdecongestant measurements. A congestion factor is calculated as a percent change in the predecongestant and postdecongestant area and volume measurements. The congestion factor is calculated using the following formula¹¹:

$$\text{Congestion Factor} = \frac{(\text{Postdecongested Area or Volume}) - (\text{Predecongested Area or Volume})}{(\text{Predecongested Area or Volume})}$$

Using this factor, nasal obstruction may be graded relatively as normal, mild, moderate, severe, or markedly severe.¹¹ Comparing the measurements made before and after administering an intranasal decongestant helps to differentiate between an inflammatory mucosal swelling (as seen in allergic rhinitis when the congestion factor is high, indicating a significant increase in the postdecongestant area) and a structural defect (as with a nasal septal defect, which has a low congestion factor representing minimal change between the predecongestant and postdecongestant measurements).¹²

Acoustic rhinometry may be used to evaluate adults, children, and infants. The patient begins by gently blowing his or her nose to clear secretions, sits upright, relaxes, and keeps the head stable (Fig 2). A disposable nosepiece that comes in several sizes is connected to the fixed dimension sound tube and is placed against the nasal inlet to form a tight acoustic seal. A water-soluble gel or paraffin wax is used to provide a better seal with the nosepiece.¹³

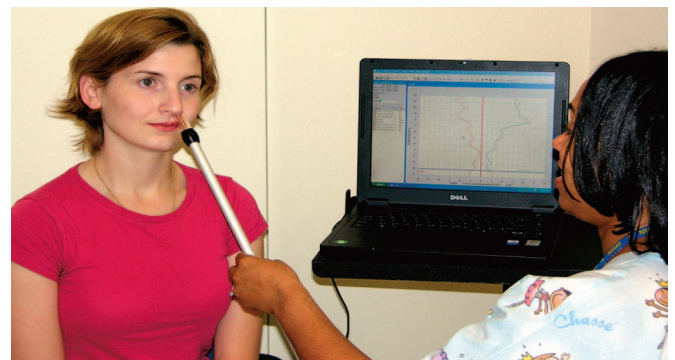


Figure 2. The acoustic rhinometry apparatus, showing the sound tube with a disposable nosepiece forming a tight acoustic seal with the left nostril and the corresponding rhinogram on the computer monitor. The patient is sitting up, relaxed, holding her breath, and holding her head stable.

ACOUSTIC RHINOMETRY IN INFANTS

More recently, a specialized miniprobe was designed, which accurately measures nasal area and volume in infants. The miniprobe has a flexible shaft, the end of which has a circular tip that forms a tight seal with the infant's nose.^{14,15} Studies in infants have shown that the miniprobe is well tolerated and nasal cavity measurements using this specialized infant probe have excellent repeatability and high reproducibility.¹⁴

FACTORS THAT AFFECT MEASUREMENTS

A number of factors lead to measurement variations when acoustic rhinometry is used. One common reason for measurement inaccuracy is an air leak between the nosepiece and the nose¹⁶; another is the presence of nasal secretions. Measurement in a recumbent position itself leads to increased nasal congestion caused by neck vein compression and hydrostatic pressure changes in the nasal mucosal blood vessels.^{17,18} Increased variability occurs when head frames or head stabilizers are used compared with measurements performed without these stabilizing devices. Head frames and stabilizers may compromise the ability to perform fine head movements, which allows for an effective seal to be formed between the sound tube and the nose. Similar variability is observed when the patient is allowed to hold the sound tube against the nostril during testing.¹⁹

Nasal cycling, a centrally mediated pattern of alternating nasal congestion and decongestion, is a common cause of physiologic variation in measurement.^{20,21} Exercise causes nasal mucosal decongestion; the effect of a 15-minute exercise challenge at 75% of the maximum heart rate results in a decrease in congestion similar to that seen with a nasal decongestant such as oxymetazoline hydrochloride.⁵ Ambient noise levels above 60 dB decrease measurement repeatability and result in sudden distortions in the graphically generated waveform. This results in "noise artifacts."²² An increase in ambient temperature may cause sound waves to travel faster.²³ An increase or decrease in body temperature by more than 1.5°C may result in nasal mucosal shrinkage or congestion, respectively.^{22,24}

Pressure changes caused by heavy breathing or swallowing during the test also lead to inaccuracies.²² Studies have reported that the minimal CSA decreases during inspiration and

increases during expiration. This difference, however, is minimal during quiet breathing. The recommended technique is thus to perform the test during a brief pause in breathing to increase accuracy. The sound tube should be held parallel to the nasal floor to help obtain an accurate measurement. Use of a miniprobe in infants and children (up to 3 years old), who cannot hold their breath, increases measurement accuracy.²²

VALIDATION

Computed tomography (CT) has validated acoustic rhinometry for up to approximately 6 cm into the nasal cavity.²⁵ Inaccuracies observed beyond 6 cm may be due to distortion of the reflected sound wave as it travels through the osteomeatal complex to the maxillary sinuses. Acoustic rhinometry has also been validated by CT in both anatomical and inflammatory conditions, including nasal septal deviation,²⁶ turbinate hypertrophy,²⁷ and chronic sinusitis.²⁸ A strong correlation in area and volume measurements has also been observed between acoustic rhinometry and magnetic resonance imaging (MRI) in the decongested nose. This correlation, however, was lower in the nondecongested nose in one study,²⁹ possibly due to nasal cycling.²⁰ Reproducibility of results of nasal cavity measurements by acoustic rhinometry is significantly increased if the test is performed by a trained operator under controlled conditions.¹³

COMPARISON TO OTHER METHODS

During the past several decades, a number of methods have been developed that objectively measure nasal obstruction. Table 1 provides a comparison of some of these techniques.

Rhinomanometry measures resistance to nasal airflow and includes both anterior and posterior techniques. In anterior rhinomanometry, the pressure-sensing probe is placed in one nasal cavity and airflow is measured in the contralateral side. In posterior rhinomanometry, the pressure-sensing probe is placed transorally between the tongue and hard palate. This technique measures airflow in both nasal cavities simultaneously. Introduction of the pressure-sensing probe toward the pharynx may cause a gag or suction reflex, which sometimes limits its use,⁹ especially in children. Rhinomanometry may be performed passively, where an extrinsic airflow source is used, or actively, where airflow is generated by a

Table 1. Comparison of the Various Methods Used to Objectively Measure Nasal Obstruction

Methods	Effort	Training and cooperation	Type of measurement	Invasive
AR	—	+	Static, nonphysiological	No
RS	++	++	Static, nonphysiological	Yes
OR	—	+	Dynamic, physiological	No
RM	—	++	Dynamic, physiological	No*
PNIF	+++	+++	Dynamic, physiological	No
PNEF	+++	+++	Dynamic, physiological	No

Abbreviations: AR, acoustic rhinometry; RS, rhinostereometry; OR, optical rhinometry; RM, rhinomanometry; PNIF, peak nasal Inspiratory flow; PNEF, peak nasal expiratory flow.

Symbols: —, none; +, minimal; ++, moderate; +++, significant.

* Active posterior rhinomanometry may be considered invasive.

patient's tidal breathing; however, not all patients are able to master the technique.

A comparison of acoustic rhinometry and rhinomanometry shows that in patients with allergic rhinitis, acoustic rhinometry appears to have advantages over anterior rhinomanometry in quantifying nasal obstruction during nasal provocative testing.³⁰ Rhinomanometry may overestimate nasal airway resistance in severe nasal blockage, which is frequently observed during nasal provocation testing.³⁰ Acoustic rhinometry is more sensitive and more specific than rhinomanometry in diagnosing obstruction in a patient with a structural anomaly, such as nasal septal deviation.³¹ Rhinomanometry also requires nasal airflow to measure resistance that may be absent in a severely congested nose, compromising measurement accuracy. However, in a subset of patients with perennial allergic rhinitis, acoustic rhinometry is not superior to anterior active rhinomanometry in quantifying nasal obstruction during nasal provocation testing.³² A significant number of authors appear to agree that acoustic rhinometry and rhinomanometry are indeed complementary techniques.^{33,34}

Optical rhinometry is a light-based technique that uses a monochromatic light emitter to trans-illuminate the nasal tissue. The emitted light is absorbed by hemoglobin contained in erythrocytes within blood in the nasal mucosa. A sensor on the contralateral side detects light that is not absorbed by the nasal mucosal tissue. By this technique, the nasal mucosal swelling can be monitored in real time, as during nasal provocation testing.³⁵

Rhinostereometry is an optical-based technique that measures anterior nasal patency. The nasal cavity is visualized with a surgical microscope that has horizontal scaled markings in millimeters on its eyepiece. This enables the examiner to directly measure the mucosal tissue swelling. The estimation process is time-consuming and not commonly used.³⁶

Peak nasal inspiratory and expiratory flow measures the nasal airflow. Both are dependent on the patient's pulmonary reserve volume and on the examiner's subjective decision as to which is the patient's best effort required to reach maximum airflow. The measurement apparatus is relatively inexpensive and portable and hence may be used at home for

monitoring nasal cavity airflow. During peak nasal expiratory flow measurements, nasal secretions may be inadvertently introduced into the flow-meter, leading to erroneous measurements.³⁷ Patient fatigue on subsequent measurements also contributes to measurement variability.

Radiographic imaging and endoscopy accompanied by a clinical examination are generally used to diagnose adenoidal hypertrophy in children. In this case, acoustic rhinometry is as good as lateral radiography of the adenoids, nasopharyngeal MRI,³⁸ and nasal endoscopy.³⁹ In addition, it is not invasive and does not expose the patient to radiation. Rhinohygmometry, oscillometry, audiometric rhinometry, and echomanometry are other techniques that have also been used to measure nasal obstruction. However, a few studies have detailed their use in the measurement of nasal cavity dimensions.

USES OF ACOUSTIC RHINOMETRY

In the 1970s, acoustic reflection techniques were primarily used to evaluate the lower airways, including measurement of the extent of tracheal stenosis⁴⁰ and the pharyngeal area in individuals with obstructive sleep apnea.⁴¹ The spectrum of application for acoustic techniques has expanded considerably since then. The first comprehensive article describing acoustic rhinometry was published in 1989.⁴² Since then, more than 500 publications on acoustic rhinometry have appeared in the literature (Table 2). Acoustic rhinometry is currently used to examine nasal dimensions in allergic rhinitis, evaluate therapeutic interventions and responses, compare preoperative and postoperative surgical outcomes, and examine patients with sleep disorders. Acoustic rhinometry is used to measure obstruction during nasal provocation testing⁴³ and monitor the effect of exposure of the nasal mucosa to chemical compounds,⁴⁴ hypertonic saline provocation,⁴⁵ smoking,⁴⁶ and histamine.⁴⁷ Acoustic rhinometry is used to monitor the effect of dust exposure on the nasal mucosa in office surroundings⁴⁸ and construction work.

Specifically, acoustic rhinometry is used to quantitate responses to intranasal steroids^{49,50} and the efficacy of topical decongestants.⁵¹ Acoustic rhinometry has also been used to

Table 2. Overview of Publications in Peer-Reviewed Journals on Acoustic Rhinometry

Studies	No. of patients	Results
Provocation	69	Nasal challenge studies
Evaluation of nasal allergies	62	Increased nasal mucosa reactivity to allergens in patients with allergic rhinitis
Therapeutic efficacy	61	Intranasal steroids, leukotriene receptor antagonists, decongestants, and external nasal dilator strips
Anatomic or surgical	54	Septoplasty, rhinoplasty, turbinoplasty, polypectomy, and uvuloplasty
Environmental exposure	26	Detrimental effects of dust, fragrance, bioaerosol, and paper dust
Validation	15	Validation of measurements by comparison to CT and MRI
Sleep	12	Sleep disordered breathing and obstructive sleep apnea
Endocrine	5	Nasal mucosal changes during pregnancy and menstruation
Central nervous system	1	High spinal cord injury leads to nasal obstruction

Abbreviations: CT, computed tomography; MRI, magnetic resonance imaging.

monitor topical desensitization with intranasal lysine-aspirin in individuals who are aspirin sensitive and have nasal polyps,⁵² to follow treatment of fungal rhinosinusitis with fusicongine spray,⁵³ and to evaluate the response of nasal polyps to montelukast in patients with asthma.⁵⁴

In the surgical field, acoustic rhinometry is used in the preoperative and postoperative evaluation of patients undergoing septoplasty,⁵⁵ turbinoplasty,⁵⁶ rhytidectomy,⁵⁷ reduction rhinoplasty,⁵⁸ adenoidectomy, and tonsillectomy.⁵⁹ It is useful in assessing congenital deformities such as cleft lip, cleft palate,⁶⁰ and cleft nose.⁶¹ Acoustic rhinometry has been used to preoperatively and postoperatively follow laser-assisted uvulopalatoplasty⁶² and nasal polypectomy.⁶³ It may be used to evaluate neonatal emergencies such as choanal atresia.⁶⁴

Acoustic rhinometry has also found applications in other fields. Patients with sleep disordered breathing have been evaluated by acoustic rhinometry.⁶⁵ Acoustic reflection techniques are thus used as objective measures of upper airway narrowing in people with sleep apnea and snoring.⁶⁶ Acoustic rhinometry has also shown variability in nasal dimensions during pregnancy⁶⁷ and menstruation caused by hormonal changes.⁶⁸

NASAL PROVOCATION TESTING

Nasal provocation testing is used in both research and clinical settings. Standardized provocation testing is considered by some to be critical in the diagnosis of occupational rhinitis and in some instances allergic rhinitis.⁶⁹ Provocation testing may also be used to monitor the efficacy of allergen immunotherapy, as well as response to pharmacotherapy.

The provocation test begins with an evaluation of the nasal cavity by acoustic rhinometry or rhinomanometry to exclude structural nasal defects and to obtain baseline nasal measurements. Under standardized conditions and within a controlled environment, a metered pump spray may be used to deliver the allergen to the nasal mucosa. A positive test result is evidenced by increased nasal obstruction as measured by acoustic rhinometry or by increased resistance to nasal air flow as measured by rhinomanometry. With acoustic rhinometry, the CSA at the anterior end of the inferior turbinate (ie, CSA2) is most sensitive in monitoring the response to nasal allergen provocation.⁹ Bilateral nasal provocation and the summation of the right and left CSA2 have been shown to be more sensitive and specific than unilateral measurement of the more obstructed nasal cavity.⁷⁰

CONCLUSION

Acoustic rhinometry is a safe, rapid, and noninvasive technique that requires minimal patient cooperation and effort and no patient training. It may be used in the evaluation of adults, children, and infants. It may be performed on a severely congested nose, since it does not require nasal airflow. Measurements by acoustic rhinometry have been validated by comparison to CT and MRI. Compared with CT and MRI, acoustic rhinometry is more rapid, may be performed at the

bedside, and, unlike CT, does not expose the patient to radiation. Clinically, acoustic rhinometry is useful to diagnose rhinitis, evaluate nasopharyngeal surgical outcomes, and monitor response and adherence to medical therapies. Acoustic rhinometry continues to be used in research endeavors because it is validated and objective. Thus, acoustic rhinometry is a logical choice for the objective measurement of area and volume in diseases of the nasal airways.

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Objectives: After reading this article, participants should be able to demonstrate an increased understanding of their knowledge of allergy/asthma/immunology clinical treatment and how this new information can be applied to their own practices.

Participants: This program is designed for physicians who are involved in providing patient care and who wish to advance their current knowledge in the field of allergy/asthma/immunology.

Credits: ACAAI designates each Annals CME Review Article for a maximum of 2 category 1 credits toward the AMA Physician's Recognition Award. Each physician should claim only those credits that he/she actually spent in the activity. The American College of Allergy, Asthma and Immunology is accredited by the Accreditation Council for Continuing Medical Education to sponsor continuing medical education for physicians.

CME Examination

1–6, Uzzaman A et al. 2006;97:745–752.

CME Test Questions

1. Which of the following is associated with a high nasal congestion factor?
 - a. adenoidal hypertrophy
 - b. septal defect
 - c. polyposis
 - d. choanal atresia
 - e. allergic rhinitis
2. Cross-sectional area 2 on the rhinogram anatomically corresponds to which of the following?
 - a. inferior turbinate
 - b. nasal valve
 - c. nasal aperture
 - d. middle turbinate
 - e. superior turbinate
3. Which of the following is a common cause of physiologic variability in measurement of nasal cavity dimensions by acoustic rhinometry?
 - a. air leak between nose and nosepiece
 - b. nasal cycling
 - c. septal defect
 - d. use of head frames
 - e. sound tube held perpendicular to nasal cavity floor
4. Which technique measures nasal resistance?

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- a. acoustic rhinometry
b. optical rhinometry
c. rhinomanometry
d. peak nasal inspiratory flow
e. magnetic resonance imaging
5. Which of the following results in a decrease in nasal obstruction similar to that seen with a nasal decongestant?
- a. decrease in body temperature
b. heavy breathing
c. swallowing
d. exercise
e. recumbent position
6. All of the following are true regarding acoustic rhinometry except:
- a. used to evaluate surgical outcomes
b. allows measurement of nasal obstruction
c. used as an educational technique
d. may monitor patient compliance
e. use restricted to adults
- Answers on page 799.**
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