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Assessing Nasal Air Flow

Options and Utility

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Abstract

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This article focuses on the tools that are available to assess nasal airflow, their utility in clinical practice, and comparison between them. Assessment of the nasal airway traditionally relied on history and physical examination only. Recently, tools have been developed that aid the physician in completing an assessment by measurement of parameters that are directly or indirectly related to airflow. Many physiologic and pathologic conditions can influence the amount of airflow or nasal airway resistance. These conditions can include normal changes, such as the nasal cycle, or pathology, such as septal deviations, turbinate hypertrophy, tumors, synechiae, nasal congestion or obstruction, allergies, nonallergic rhinitis, and sinonasal polyposis. Objective measures can be used to assist the clinician to diagnose and treat nasal complaints and also for objective quantification for research.

Keywords: nasal cavityairway resistancenasal airflownasal airway

To understand abnormal nasal physiology, a brief description of nasal physiology is necessary. The nose is lined by highly vascular mucosa containing arterioles, arteriovenous anastomoses, and venous sinusoids. Swelling of the erectile tissue, which is concentrated in the anterior portion of the inferior turbinate and the middle turbinate, is responsible for nasal congestion.

This is under direct control via humeral factors and indirect control by sensorineural input ([1]). Taking the upper and lower airway together, nasal airway resistance constitutes about 50% of the total airway resistance ([2]). For this reason, changes in nasal resistance will impact overall respiratory function.

The nasal cycle is a physiological phenomenon that causes alternate nasal congestion and decongestion on opposing sides of the nose. Ideally, the right and left side of the nose in each cycle should have a similar airflow, resistance, and amplitude, and volume changes in a reciprocal fashion ([3]). There are wide variations of this scheme, but most reported subjects exhibit spontaneous and reciprocal changes in unilateral airflow ([4], [5]), as demonstrated in Figure 1. The nasal cycle usually lasts between 4 to 6 hours; however, it has been demonstrated that fluctuations in nasal patency as short as 10 minutes or as long as several days can occur ([6]). Most normal subjects do not consciously realize that one side or the other is alternately congested relative to the other, and only notice a difference consciously if there is obstruction on one or both sides. Objective measurements can be taken of each side separately, or both together, depending on the methods used.

Figure 1.
Typical tracing of the nasal cycle as measured by acoustic rhinometry. Initially, both nasal cavities seem ...
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To assess airflow, a brief understanding of the internal nasal valve (NV) is needed. The front portion of the nasal cavity from the nostril to the NV is the area of greatest airflow resistance ([7]).This is the narrowest area of the nasal cavity ([8]) and thus is very important for nasal physiology and the assessment of obstruction ([9], [10]).

Mlynski and colleagues ([10]) studied airflow in nasal models and reached the conclusion that the nasal vestibule, or valve, is shaped like a tube, which redirects the nasal flow that comes from the front and the sides to create laminar flow. The NV is a three-dimensional structure that is usually located 1 to 1.5 cm from the nostril anteriorly. The anterior limit is the ostium internum, which is the orifice seen by anterior rhinoscopy. The lateral limit is the lower border of the upper lateral cartilage, and the medial limit is the septum. Its posterior limit includes the pyriform aperture and the nasal cavity floor, which also has erectile tissue ([11]). The isthmus nasi is the second portion of the NV, which is composed of the anterior portion of the inferior turbinate and the portion of the nasal septum that passes through the pyriform aperture. These areas also contain erectile tissue and are located about 1.65 to 2.65 cm from the nostril ([12]).

SUBJECTIVE SENSATION OF NASAL PATENCY AND NASAL RESISTANCE

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The relationship between objective nasal resistance and subjective nasal patency as felt by the patient has been the discussion of several articles (9, 13–23). Studies have shown that marked sensation of increased airflow was demonstrated when substances such as camphor, eucalyptus, L-menthol, vanilla, or lignocaine were applied to the nasal or palatal mucosa. The sensation of patency under these conditions is not accompanied by a change in objective measurements, such as rhinomanometry (RM) (9, 21–23). A similar but opposite situation is also demonstrated by applying local anesthesia to the vestibule, which causes decreased sensation of nasal patency, while no change in the objective rhinomanometric measurements are observed (9, 21–23). For this reason, it has been postulated that the objective assessment of nasal airway patency can never predict the actual subjective sensation of nasal patency. However, a recent systematic review by André and colleagues (24) reviewed articles in the literature that were level II-a or II-b comparing subjective and objective nasal airflow measures. They concluded that that the chance of a correlation is greater when each nasal passage is assessed individually and when obstructive symptoms are present. Because sensation is blocked by topical anesthetics, the anesthetized nose is not a fair physiologic comparison of the ability to judge nasal patency by any particular method. It only demonstrates that an intact neural and sensory system must be present to assess nasal patency in normal subjects.

Only recently have validated questionnaires on subjective assessment of nasal airway patency become available. These subjective scales include the SNOT-22 (Sino-Nasal Outcome Test) and the NOSE test (Nasal Obstruction Symptom Evaluation test) (25, 26). For this reason, the majority of the articles did not use these validated tests in their analyses and instead used nonvalidated subjective scores or questionnaires.

SUBJECTIVE ASSESSMENT OF THE NASAL AIRWAY

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History and Physical Examination

The assessment of the nasal airway begins with a history and physical examination of the patient. In the history, it is important to ask about specific rhinitis symptoms, such as congestion, blockage, rhinorrhea, postnasal drip, sneezing, and itching, and to investigate a potential allergic source for the nasal obstruction. It is also important to ask about history of prior surgeries, the intake of prescribed medications, and over-the-counter medicines or herbs (27).

Examination of the patient will also help in assessing the potential of an allergic etiology if the patient exhibits classic allergic shiners or the allergic salute. The nose should be examined starting with the external examination and moving on to anterior rhinoscopy. The external appearance of the nose should note external deviations, previous rhinoplasties, and tip ptosis, which, if severe, can affect airflow. The patient's internal NV, which is the smallest cross-sectional area of the nose, should be examined carefully. It can often be examined by simply lifting the nasal tip superiorly (28). Another test that can be done is the Cottle maneuver, which is performed by retracting the cheek area on one side and checking if the patient's symptoms disappear; a positive test suggests that the obstruction is at the NV (Figure 2). In cases of

synechiae in the NV area, a false-negative test might occur (28). In addition to the physical examination, a diagnostic endoscopy with a flexible or rigid endoscope can be very valuable. This is best performed before and after decongestion of the nose (Figure 3). Nasal obstruction that is due to inflammatory diseases of the inferior turbinates will usually improve after decongestion (29). Lack of response to decongestant usually indicates a structural obstruction, such as a septal deviation, or bony hypertrophy of the turbinates. It may also indicate inflammatory conditions that do not respond to decongestants, such as rhinitis medicamentosa and diffuse nasal polyposis.

Figure 2.
(*A*) Performance of the Cottle maneuver. View of the right nasal valve (*B*) before and (*C*) after. (Adapted ...
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Figure 3.
The inferior turbinate (*A*) before and (*B*) after decongestion with oxymetazoline. (Adapted from referenc...
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Subjective assessment of the nasal airway can be accomplished by using preestablished scales, such as the nasal obstruction visual analog scale (NO-VAS) (30). There are validated outcome instruments that include nasal obstruction, such as the SNOT-22 and the NOSE (25, 26). Not all nasal outcome quality-of-life surveys include nasal obstruction, despite the fact that nasal blockage is the most common complaint of patients with allergic rhinitis. The source of the nasal obstruction may not always be evident by history and physical examination, and further objective assessment might be needed.

OBJECTIVE EVALUATION OF THE NASAL AIRWAY

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Quantitative objective measures may be used to assess the airway. Zwaardemaker in 1894 described "hygrometry," which was the first objective method to assess nasal airflow (31). It is a measurement of the diameter of the fog that is caused by breathing onto a mirror. The second objective test, which was developed by Spiess in 1902, is the "hum test." This tests the change in the timbre of the sound that is produced while occluding the decongested nasal side when the patient is producing a humming sound (32). These tests are of historical interest only. Computed tomography (CT) volumetry is another relatively new test that is used to assess

nasal blockage, but because of radiation exposure, it has not been used frequently. Today, we use one or more of the following tests:

- Peak nasal inspiratory flow (PNIF)

- Acoustic rhinometry (AR)

- Rhinomanometry (RM)

- Odiosoft Rhino (OR)

PNIF

PNIF is a noninvasive method ([Figure 4](#)) that measures, in liters per minute, the nasal airflow during maximal forced nasal inspiration ([33](#)).The instrument can be coupled to a simple computer and a recording device to keep records of the results similar to a handheld spirometer. PNIF may be inaccurate because it relies on the patient's cooperation and correct instruction by the investigator ([33](#)). It also does not measure the airflow during normal breathing without maximal effort and as such will be affected by patients with respiratory compromise due to other upper or lower airway obstruction. The method has been suggested to be reliable and reproducible in concordance with the other objective tests, such as AR.

Figure 4.
Nasal inspiratory flow meter used by a patient. (Adapted by permission from Clement Clarke Internatio... [More]

AR

AR is another objective test. First described by Hillberg and colleagues in 1989 ([32](#)), AR is currently the most common test that assesses nasal geometry ([34](#)). It is a noninvasive, rapid, and inexpensive test that measures the cross-sectional area (CSA) of the nose as a function of the distance from the nostril ([Figure 5](#)). It is used to calculate nasal passage volumes, which is useful for patients who have anatomical obstruction, such as nasal polyposis or septal deviation ([30](#), [34](#), [35](#)). Contrary to NPIF, AR requires minimal patient cooperation and can also be performed during normal sleep or under general anesthesia, providing a measure of the nasal airway in its natural state. It typically does not require sedation or anesthesia and can be performed on both children and adults.

The principle of AR relies on analyzing the reflections of the sound waves after entry into the nose. The distortions observed in the sound wave are typically the result of the variations in the size and contour of the nasal cavity. The time when these deflections occur is usually an estimate of the distance from the nostril and their magnitude is the estimate of the change in the cross-sectional area of the nose. These are constructed into a rhinograph (Figure 6) by the computer (36). AR's best accuracy is typically in the first 5 to 6 cm anteriorly from the nostril (37). For this reason, it is useful for measurements of the NV, which is the narrowest area inside the nose (7, 12).

Figure 6.
A sample acoustic rhinometry graph. Cross-sectional area (CSA) 1 is believed to represent the nasal valv...

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Equipment for AR.

The equipment used in AR is described by Hilberg and colleagues (32). These are the nosepiece, sound source, wave tube, microphone, filter, amplifier, analog-to-digital converter, and a computer. The microphone detects the reflected acoustic signals ("clicks"), which are then used by the digital converter to be reported on the computer as the rhinograph.

Technique of AR.

AR is typically performed in a quiet room with the patient relaxed for 10 to 20 minutes to adapt to room temperature and humidity. It is important to have the head of the patient held steady when performing the test. Several trials have used a head frame, but this approach did not provide better results (38). The equipment is first calibrated by using a test signal with the patient asked to hold his/her head steady and to fixate gaze on a distant point. The nasal tube is aligned in the same axis as the nose and the nosepiece is then held against the naris on the side to be tested first. Application of lubricating jelly to the nosepiece is preferable to provide a good seal without causing any distortion of the external nasal anatomy. Repeated acoustic clicks are generated, with each one lasting 10 seconds to ensure reproducibility of the curve obtained by the computer. Three sets of sampling are usually taken on each side and then averaged by the computer. Decongesting the nose with topical decongestants is helpful to delineate a potential reversible cause of the nasal obstruction. Decongestion helps quantify (39, 40) and assist in localizing the mucosal component of nasal congestion. The measurements are repeated after decongestion. Both fixed (structural or irreversible) and nonfixed (mucosal or reversible) components can be determined in the same rhinograph. Multiple areas of

constriction, usually up to three, can be identified, providing a topographic map of the internal nasal anatomy.

The acoustic rhinograph.

The tracing in Figure 6 is the acoustic rhinograph obtained from the computer on completion of the test. The distance from the nostril is represented on the x-axis with position of the nares at 0 cm. The cross-sectional area of the nose is represented on the y-axis.

Generally, only the first 6 cm are used for interpretation, with the best accuracy being in the first 5 cm (37). As seen in the graph, there are three "notches" or "valleys" in the curve. There are differences in the terminology between the United States and the European literature. In the United States, the narrowest areas in the nasal cavity are referred to as valleys, or minimal CSA 1, 2, and 3. In the European literature, this area is described as a "rising W" or an "I-notch," referring to an Isthmus notch.

Interpretation of the acoustic rhinograph.

In most normal subjects, CSA 1 corresponds to the area of the internal NV. CSA 2 correlates with the location of the anterior head of the inferior or middle turbinate. CSA 3 correlates with the midposterior end of the middle turbinate. Relative changes in volume and area correlate with the subject's subjective sensation of nasal blockage compared with absolute volumes/areas. Therefore, measurements of the individual change in congestion can give useful clinical information. The "congestion factor" is such a measurement. The congestion factor gives an estimate of the irreversible or nonmucosal components compared with the reversible components of nasal airflow obstruction, which can help tailor the treatment toward medical and/or surgical therapies.

The senior author (J.P.C.) has demonstrated in a previously published article a method to quantify nasal congestion by calculating the "congestion factor" (39). This consists of obtaining the values at CSA 1, 2, and 3, which are approximately at distances of 2, 4, and 6 cm, respectively. The measurements are repeated 10 minutes after decongesting the nose with 0.05% topical oxymetazoline. The following equation is then used to determine the congestion factor:

$$\text{Congestion factor} = (\text{decongested CSA 2 value} - \text{baseline CSA 2 value} / \text{baseline CSA 2 value}).$$

The congestion factor is then categorized as either normal, mild, moderate, severe, or markedly severe by comparing it with a grading scale. Normative values for this scale are derived from prior published data (41). A difference of two standard deviations or more between the CSA 2 measurement before and after decongestion is considered abnormal (39).

A recent systematic review to assess the anatomical correlates of the notches in AR affirms that the first notch is the NV and the second one is the anterior end of the inferior turbinate (42). In this systematic review, it was also reported that some articles located the first notch corresponding to the nostril, whereas the second notch corresponds to the NV. More studies

are needed to confirm the locations of the notches on the rhinograph. Some of the discrepancy may be explained by variations in the individual's anatomy as shown in [Figure 7](#) or the use of different nosepieces. Earlier studies used a nosepiece that fit inside the nostril (internally placed), whereas later studies have used external nosepieces that do not protrude into the NV ([Figure 8](#)).

Figure 7.
Variations in the location of CSA2. (*A*) The inferior and middle turbinate are directly overlying in the verti...
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Figure 8.
External nosepieces used for acoustic rhinometry with different shapes and sizes.
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There is a strong correlation between the CSA as measured by the AR and magnetic resonance imaging (MRI) after nasal decongestion ([34](#), [43](#)) and CT scan as measured in cadaver studies ([34](#)). Volumetric measurement of nasal stuffiness (using computed tomography volumetry (CTV) and MRI) ([34](#), [37](#)) were found to be statistically significant in the anterior and midnasal cavities and become unreliable posteriorly when comparing them to acoustic rhinometric measures. This may also be caused by loss of acoustic energy posteriorly ([2](#)). In addition, prior studies by the senior author (J.P.C.) and others correlated the measurements obtained by AR and those of CT scans ([2](#), [44](#)), MRI ([2](#), [41](#)), and nasal endoscopy in normal volunteers ([45](#)).

RM

RM is another objective measure of nasal airflow that is considered dynamic. It involves the simultaneous measurement of transnasal pressure and airflow. It is only because there is a pressure difference between the nasopharynx and the outside of the nose that airflow occurs. Nasopharyngeal pressure is the only pressure that changes during inspiration and expiration and hence creates a transnasal pressure across the nose. Multiple factors affect nasal airflow. These include the length of the nose, cross-sectional area, transnasal pressure, and whether the flow is turbulent or laminar ([46](#)). Cross-sectional area is a major factor that influences the nasal airflow.

Equipment of RM.

Airflow is measured by means of a tachometer and a pressure transducer. The pneumotachometer is a resistor that induces laminar flow across the nose with a drop that varies linearly with the flow. It may be attached to a nozzle that is inserted into the nasal vestibule. The pressure transducer converts the pressure differential into an electrical signal and results in a corresponding change in the output voltage, which is read by a recording device that is usually a computer.

There are three different techniques to measure transnasal pressure: anterior, posterior (per oral), and postnasal (per nasal) RM. The difference between these three techniques is the location of the pressure detector at the back of the nose. In the anterior technique, the pressure detector is placed at the opening to the nostril that is not being tested. In the posterior technique it is placed in the posterior oropharynx, and in the postnasal technique it is placed in the posterior nose passing through one of the nostrils.

Technique of anterior RM.

The measurements are usually obtained with the patient in a sitting position and after a 20-minute adaptation period. The patient should be spontaneously breathing at rest during the measurements. The mask that is used should not leak and should not deform the nose, and the nasal connections should not alter the shape of the nasal entrance. Active and passive techniques of assessment of the nasal airflow can be used with RM. In active RM technique, which is the most commonly used method of RM (47), the patient is asked to breathe through one nasal cavity while the narinochoanal (naris to choana) pressure difference of the contralateral nasal cavity is assessed. The passive RM technique involves measuring the pressure for each nasal cavity separately at an airflow of 250 cm^3/s.

Recording pressure and flow simultaneously over a period of time allows for the measurement of the mean pressure and the volume of each breath. The work of breathing can be determined (pressure × flow) and resistance (pressure/flow) for each breath is determined. The resistance that is measured can be compared with total resistance and/or with the resistance of the opposite side of the nose. The curve obtained by the plot is S-shaped. The x-axis represents the pressure differential, and the y-axis represents the flow. The "mirror image" using four quadrants of the graph is accepted as the standard representation in active RM. Figure 9 (48) shows the RM graph where the curve on the right of the flow axis represents the change in inspiration and the curve on the left represents the change in expiration. The right nasal cavity is represented on the upper part of the pressure axis and the left nasal cavity on the lower part of the pressure axis.

Figure 9.
Typical curve of the nasal valve with rhinomanometry. (Adapted by permission from reference 48.)

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The current standardized technique is four-phase RM as seen in [Figure 10](). It involves studying, separately, the ascending and descending parts of the curves during inspiration and expiration.

Figure 10.
Four-phase rhinomanometry. This technique provides supplementary information; the ascending and d...
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Interpretation of RM.

Nasal congestion can be quantified in terms of nasal airway resistance in this method. According to international standards, resistance should always be given at a fixed pressure of 150 Pa. In certain pathological conditions in which the pressure of 150 Pa cannot be obtained, then lower pressures of 75 or 100 Pa can be used but need to be taken into account when interpreting the results. For four-phase RM, resistance is determined for phase 1, which is the ascending inspiratory phase, and phase 4, which is the descending expiratory phase, by use of the highest possible flow at a pressure of 150 Pa.

It has been reported in the literature that the mean total resistance in normal subjects ranges between 0.15 and 0.39 Pa/cm^3/s ([49]()), with a mean of 0.23 Pa/cm^3/s. For this reason, a total nasal airway resistance of 0.3 Pa/cm^3/s is accepted as the upper limit of normal ([50]()). The range of unilateral nasal airway resistance in healthy volunteers when recorded over 6 to 8 hours has been noted to have a fourfold fluctuation due to the nasal cycle ([50]()). As such, it is not informative to quote a single normal value for unilateral nasal airway resistance ([51]()).

Clinical Application of AR and RM

The use of RM has been limited clinically, but it is an excellent research tool. It can be used to measure nasal airway resistance before and after decongestion. If there is less than 35% decrease in resistance, then structural and irreversible causes of nasal obstruction must be sought. Both AR and RM are commonly used in nasal challenge studies ([52](), [53]()). Studies have shown that objective measurements can demonstrate the efficacy of intranasal steroids or antihistamines ([54](), [55]()) and can also be used for detecting correlations between nasal resistance and sleep apnea, the effect of nasal dilators on nasal resistance, and the efficacy of surgery on the NV or septal deviation ([56]()).

The acoustic rhinograph can be used as a topographic map in localizing multiple obstructions and characterizing nasal septal deviation. The clinical uses of AR have expanded over the last decade. It is also a good tool to compare preoperative and postoperative values for patients undergoing surgery such as septoplasty, turbinate reduction, facial cosmetic surgery, antrochoanal atresia repair, and tonsillectomy for pediatric sleep apnea ([57]()–[61]()). Another use is to aid in the diagnosis and treatment of sleep apnea. It can predict the tolerance of the nasal

continuous positive airway pressure in adult patients ([62](#)–[64](#)). It has been shown that subjects with a CSA that is less than 0.6 cm^2 at the head of the inferior turbinate are not able to tolerate nasal continuous positive airway pressure.

Comparison of the Two Commonly Used Objective Tests (AR and RM)

Scadding and colleagues reported comparable results between AR and RM when used as a screening tool, but patients tolerated AR more easily ([65](#)). Passali and coworkers found that RM was more sensitive and specific for patients with functional nasal obstruction, such as rhinitis. In contrast, AR was found to be more sensitive and specific when evaluating structural causes of nasal obstruction ([66](#)). The advantages and disadvantages of AR and RM are listed in [Table 1](#). There are, however, common disadvantages to both techniques, such as being operator dependent. They also are unable to diagnose tip ptosis and alar collapse because their measurements are typically distal to this site. However, AR can be used in combination with a Cottle maneuver and external nasal examination to document improvement in nasal volume with tip elevation and cheek retraction for diagnosis of tip ptosis and alar collapse.
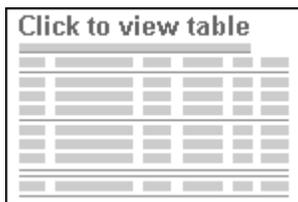
Click to view table

TABLE 1. VARIABILITY IN ACOUSTIC RHINOMETRY AND RHINOMANOMETRY
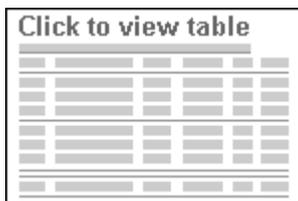
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TABLE 2. OBJECTIVE TESTS AVAILABLE TO MEASURE NASAL BLOCKAGE

OR

OR is a noninvasive objective test developed by Seren ([67](#)) that converts the frequency of sound generated by nasal airflow into cross-sectional area measurements. The principle behind this test is that nasal airflow causes a higher-frequency sound as turbulence increases ([67](#)). This technique involves the use of a microphone, nasal probe, sound card, and a computer. The subject is first asked to block one nostril, and then the nasal probe is connected to a microphone that is 1 cm from the nostril ([68](#)). Unlike AR, it is the sound generated by spontaneous breathing here that is recorded and not the reflected one. Results obtained by OR may be as accurate as those obtained by RM (68) and has also been shown in other studies to have better correlation to patient symptom scores as compared to AR ([69](#)).

A summary of all the tests discussed is listed in [Table 2](#).

Limitations and Variability Obtained with Objective Testing Using AR and RM

It is difficult in clinical practice to delineate the factors that contribute to nasal blockage and also to decide on the treatment needed. Perception of nasal flow is a subjective sensation and thus is difficult to quantify. The gold standard test would be that one that can quantify nasal airflow and that is reproducible with the strongest correlation with the subjective sensation of the patient's airflow.

There are factors that affect AR, RM, and the OR, whereas other factors affect only one test and are neutral on the others. There is not much literature published on OR, and for this reason the discussion here is primarily about AR and RM.

The accuracy of AR decreases as the distance from the nares increases, with the best accuracy in the first 5 cm ([40]). It is important to communicate with the patient that breathing and swallowing are not allowed during AR. Breathing can change the CSA estimates ([70]) or provide a high rate of artifactual traces ([71]). There are multiple factors that affect both the AR and RM, including age, height, nasal cycle, exercise, hyperventilation, breathing CO_2, posture, time of the day, medications, and smoking. These effects are summarized in Table 1.

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