Received: 6 June 2023 | Revised: 1 August 2023 | Accepted: 17 September 2023

DOI: 10.1002/lio2.1157

ORIGINAL RESEARCH

Laryngoscope Investigative Otolaryngology

Active anterior rhinomanometry: A study on nasal airway resistance, paradoxical reactions to decongestion, and repeatability in healthy subjects

Ola Sunnergren PhD[1,2] | Hanna Ahonen PhD[2] | Mats Holmström PhD[3] | Anders Broström PhD[4,5,6]

[1]Ear, Nose and Throat Clinic, Region Jönköping County, Jönköping, Sweden

[2]Centre for Oral Health, Department of Odontology and Oral Health, School of Health and Welfare, Jönköping University, Jönköping, Sweden

[3]Department of Clinical Science, Intervention and Technology (CLINTEC), Division of Ear, Nose and Throat Diseases, Karolinska Institute, Stockholm, Sweden

[4]Department of Nursing, School of Health and Welfare, Jönköping University, Jönköping, Sweden

[5]Department of Clinical Neurophysiology, University Hospital Linköping, Linköping, Sweden

[6]Department of Health and Caring Sciences, Western Norway University of Applied Sciences, Bergen, Vestlandet, Norway

Correspondence
Ola Sunnergren, Ear, Nose and Throat Clinic, Region Jönköping County, Öron-, näs- och halskliniken, Länssjukhuset Ryhov, 551 85 Jönköping, Sweden.
Email: ola.sunnergren@ju.se

Funding information
The Academy of Health and Care in Region Jönköping County, Grant/Award Number: FUTURUM- 803421

Abstract

Objectives: Anterior active rhinomanometry (AAR) is widely used in Swedish routine clinical practice to decide if septoplasty is necessary. The scientific basis for the method needs to be strengthened. Therefore, the aims were to evaluate nasal airway resistance (NAR), paradoxical reactions to pharmacological decongestion, and test–retest characteristics of the Rhino-Comp® AAR in healthy subjects.

Methods: A prospective longitudinal design was used. AAR was performed before and after decongestion at baseline and after ≥6 months on 60 healthy volunteers. The relationships between NAR, height, weight, BMI, sex, and allergic rhinitis were evaluated by regression analyses. Descriptive statistics were used to evaluate paradoxical reactions. Test–retest and repeatability characteristics were evaluated with intra-class coefficients (ICC), Cronbach's α, and standard error of measurement

Results: No statistically significant differences were found between genders or nasal cavity sides. NAR was statistically significantly related to height. Short- and long-term test–retest characteristics were good with ICC and Cronbach's α > .75. The minimal significant difference in NAR Log10V2 values between the two measurements was 0.11 and 0.09 (long- and short-term). Paradoxical reactions to pharmacological decongestion were rare, mostly weak, and not evidently reproducible.

Conclusion: In this study, we report reference data for healthy subjects, test–retest capabilities, and the minimal relevant difference between two measurements for the Rhino-Comp® AAR, information that is vital and necessary for the appropriate use of AAR in clinical practice. An effective method for pharmacological decongestion is described and recommended for future studies and clinical practice. Paradoxical reactions to pharmacological decongestants exist but maybe without clinical significance.

Level of Evidence: NA.

KEYWORDS
active anterior rhinomanometry, nasal airway resistance, paradoxical reaction, pharmacological decongestion, Rhino-Comp®

1 | INTRODUCTION

Anterior active rhinomanometry (AAR) is a method to measure nasal airway resistance (NAR) in research and clinical practice.[1] The 2019 European position paper on diagnostic tools in rhinology states that pre- and post-decongestive AAR measurements can be used to select patients for surgical procedures, but it does not provide details on the indication and interpretation of AAR[1] and we do not know of any other report that provides robust evidence-based guidelines on how to use AAR in clinical practice. This indicates that even though AAR has been available for decades, a definite and clear role of the method in routine rhinology clinical practice and research has yet to be established.

Despite this, AAR seems to be commonly used in Swedish routine rhinology clinical practice. Data from the National Septoplasty Register in Sweden showed that 63% (6683/10608) of the registered septoplasties 2014–2022 were preceded by an AAR.[2] This data was supported by the results of a national survey[3] performed in 2021–2022 by the Swedish Rhinologic Research Alliance which showed that a majority (77%) of Swedish ENT clinics performing septoplasty used AAR in the selection process for septoplasty. The vast majority of units (80%) used the Rhino-Comp® AAR (IBBAB, Kungsbacka, Sweden). The survey also showed that all centers used pharmacological decongestion and that standardized procedures including the type and mode of administration of decongestive pharmacological drug and the time interval before testing of the decongested nose were lacking. There was nevertheless a clear consensus that AAR was of great value in the preoperative assessment of septal deviation and many clinics also reported that AAR was used to assess the outcome of septoplasty.

The Rhino-Comp® measures NAR according to the Broms model[4] which is one of the AAR techniques accepted by the 2005 European Consensus report on AAR.[5] The results are presented in a standardized report together with reference data for NAR obtained after decongestion in healthy subjects. The present reference data is problematic as it comes from a study[6] published in 1982 where decongestion was obtained by physical exercise, a decongestion method that is no longer in use in Sweden. Another limitation with the Rhino-Comp® AAR, especially if it is to be used to follow up the outcome of surgery, is that studies with a clinically relevant design on the test–retest characteristics are lacking. Another feature of AAR that needs to be further studied is the phenomenon of the paradoxical reaction to pharmacological decongestants. Many clinicians have noted subjects with an increased NAR after pharmacological decongestion but to our knowledge, there is only one study on this topic[7] using AAR, and a better understanding of the prevalence and impact of paradoxical reactions is therefore needed.

The aims of this study were to evaluate NAR values obtained with and without pharmacological decongestion in healthy volunteers, to investigate paradoxical reactions to pharmacological decongestion, and to assess the test–retest characteristics of the Rhino-Comp® AAR.

2 | MATERIALS AND METHODS

2.1 | Study design, population, and data collection

This was a prospective longitudinal study with repeated AAR measurements. Sixty volunteers, 30 women, and 30 men, all non-smokers without known nasal problems were recruited for the study. All subjects were either health care personnel or medical students at the Ryhov County Hospital in Jönköping, Sweden. Eligible subjects had to be ≥18 years old, have a self-assessed bilateral normal nasal breathing, and no history of previous nasal surgery. Subjects with allergic rhinitis were included as long as the data collection was performed outside the allergic season or without recent exposure to the allergen.

2.2 | Active anterior rhinomanometry (AAR)

AAR was performed with the Rhino-Comp® device. The Rhino-Comp® is based on the Broms model[5,8,9] with the R2 and V2 values (Figure 1) for the left and the right sides of the nose as the main outcome measures.

The AARs were performed after at least 5 min of sitting rest. We ensured that all subjects came to the measurements from quiet activities. All baseline and follow-up measurements were carried out by the

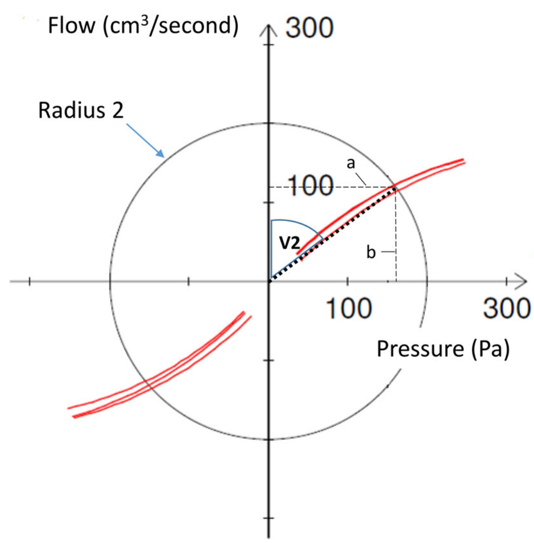


FIGURE 1 Polar coordinate flow-pressure curve from the Rhino-Comp® AAR. V2 is the angle between the flow axis (*y*-axis) and a line (the dotted line in the figure) drawn from the origin to the point where the flow-pressure curve crosses radius 200. The *R*-value is pressure (Pa)/flow (cm^3/s) measured from the point where the curve crosses radius 200 (line “a” for pressure and line “b” for flow). The V2 and the R2 are thus related as tanV2 = R2. In the original model by Broms, different scales on the *y*- and *x*-axes were used. The Rhino-Comp® results are still given as V2 and R2 values which correspond to V200 and R200, respectively, in this chart.

first author and were performed in the same room, with the same equipment, and at normal room temperature.

AARs were performed with and without pharmacological decongestion as illustrated in Figure 2. Nasal decongestion was obtained by two sprays of oxymetazoline hydrochloride 0.5 mg/mL (Nezeril®) in each nostril, followed by a waiting period of 15 min, then another two sprays in each nostril, and a final waiting period of 5 min. Each spray dose contained 0.025 mg of oxymetazoline hydrochloride, giving a total amount of 0.1 mg in each nasal cavity. At follow-up, two measurements were taken after decongestion, immediately after one another.

Transparent silicone full nasal masks were used and attention was paid to ensure that the mask did not deform the nose, especially the side where flow was measured. A rounded adhesive patch was cut to fit the nostril and to create an airtight seal for the side where pressure was measured.

Follow-up measurements (test–retest) were conducted 6 months or more from baseline.

2.3 | Questionnaires and visual analog scales

At baseline, and before the AARs, all subjects completed the Swedish versions of the Nasal Outcome Symptom Evaluation scale (S-NOSE)[10] and the Sino-Nasal Outcome Test-22 (SNOT-22).[11] Nasal patency visual analog scale (VAS) scores (graded from 1 to 10, 1 = total obstruction and 10 = total free flow) during calm and resting breathing were collected before and after decongestion (mouth closed) for both nostrils and for the left and right nostrils separately. When assessing unilateral nasal patency VAS the contralateral nostril was occluded by the tip of the thumb without deforming the nostril that was tested.

2.4 | Paradoxical reaction to pharmacological decongestion

There is no generally accepted definition of a paradoxical reaction. As Swoboda et al. defined an increase of ≥20% in NAR after decongestion as a paradoxical reaction[7] we chose to use the same definition in our study. In the present study NAR values before and after decongestion from measurements I–III were used to evaluate the prevalence and reproducibility of paradoxical reactions. For the follow-up measurements, one measurement before decongestion was made, and two measurements were made after decongestion.

3 | STATISTICS

Statistical analyses were performed in IBM Statistical Package for the Social Sciences version 27.[12] Parametric and nonparametric tests were used depending on scale level and distribution.[13,14] Due to the non-normal distribution of the V2 values they were transformed using Log10. The correlation among variables before regression analysis was assessed using Pearson's *r* and Spearman's rho.[13] To assess the V2 values before and after decongestion and to assess differences between the left and the right nostril, paired samples *t*-tests were performed. The effect sizes were estimated using Cohen's *d*. Differences among females and males were controlled by independent *t*-tests where the sex was used as a grouping variable.[13,15] Multiple regression and stepwise hierarchical regression were performed to explore the relationship between height and other possible variables affecting the V2 values and to control for height, weight, BMI, sex, and allergic rhinitis.[13,16]

To assess differences between measurements, repeated ANOVA was performed except for the pre-tests (before decongestion) where a paired sample *t*-test was used (two points of measurement).[13,16] To explore repeatability, intra-class coefficients (ICC) were calculated (two-way mixed model with absolute agreement, confidence interval of 95% with test value 0). The average value was then reported. In addition to the ICC Cronbach's alpha was calculated to estimate the internal consistency.[16–18] The standard error of measurement (SEM) was used to establish the minimal difference between two measurements that with confidence signifies a true change [MD].[17] Based on *p*-values, statistical significance was set at $\alpha < .05$.

4 | ETHICS

This study was approved by the Swedish Ethical Review Authority (2019-06015 with amendments 2022-0534-02 and 2022-05938-02). All subjects gave their signed informed consent. The study was conducted in accordance with the principles of the Helsinki Declaration.

5 | RESULTS

5.1 | General characteristics of the studied population

The baseline characteristics of the studied population are presented in Table 1. Males were taller than females and had a higher body weight. There were no statistically significant differences between men and

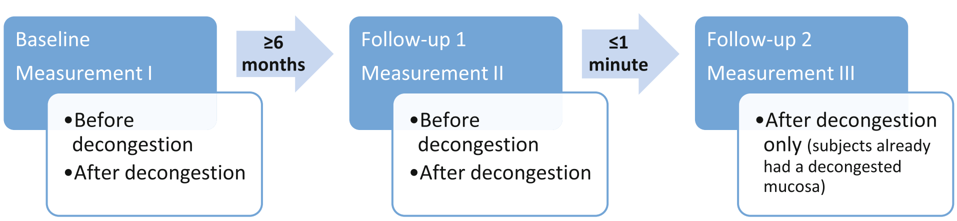


FIGURE 2 A presentation of the different NAR measurements in the study.

TABLE 1 Baseline characteristics of the studied population, $n = 60$.

Age, mean (SD)	34. 1 (10.29)
Sex, number (%)	
Female	30 (50)
Male	30 (50)
Height, mean (SD)	174.0 (10.3)
Female	166.6 (6.5)
Male	181.3 (8.0)
Weight[a], mean (SD)	71.7 (13.1)
Female	64.2 (13.4)
Male	78.4 (8.6)
BMI[a], mean (SD)	23.6 (3.7)
Female	23.3 (4.6)
Male	24.0 (2.7)
S-NOSE, mean (SD)/median (min–max)	3.5 (5.6)/0 (0–25)
SNOT-22, mean (SD)/median (min–max)	3.5 (3.5)/3 (0–14)
Nasal patency VAS[b], mean (SD)/median (min–max)	
Bilateral	9.4 (0.8)/10 (7–10)
Left side	8.7 (1.5)/9 (5–10)
Right side	8.8 (1.3)/9 (5–10)
Allergic rhinitis, number (%)	
Yes[c]	16 (26.7)
No	44 (73.3)

Abbreviations: SD, standard deviation; min, minimum; max, maximum.
[a] $n = 55$ (missing data for one male and four females).
[b] Nasal patency VAS scores were scored before decongestion.
[c] Pollen $n = 13$, pollen and dog $n = 2$, cat $n = 1$.

women regarding S-NOSE score, SNOT-22 sum, or nasal patency VAS scores at baseline.

5.2 | Nasal airway resistance

There were no statistically significant differences between the left- and the right-side NAR values before or after decongestion in any of the three measurements. Furthermore, we found no statistically significant differences between NAR values for men and women in any of the measurements (all $p > .05$). Height was found to be the strongest predictor for NAR values, followed by weight. Sex, BMI, and allergic rhinitis did not reach statistically significant unique contributions. In Figure 3, a scatter plot with a regression line for left- and right-side NAR versus height is presented. Cases were weighted ($1 - (0.5 \times$ explained variance)) to compensate for each case contributing with two values for Log10 V2 and only one for height. The equation for the regression line was $y = 2.26 - 0.00784 \times$ body height. To illustrate estimated reference intervals in healthy subjects, both 95% confidence intervals and 95% prediction limits are provided in Figure 3.

5.3 | Objective and subjective paradoxical reactions to decongestion

In a clear majority of measurements, the subjects reacted as expected to decongestion with unchanged or improved NAR values (Figures 4 and 5) and nasal patency VAS scores (Table 2). NAR values before and after decongestion differed statistically significantly, with large statistically significant effect sizes for all measurements for both the left and the right sides. The differences in nasal patency VAS scores were small, with a mean improvement of less than one step on the VAS scale for both the right and left sides of the nose.

As shown by the distribution of dots in relation to the solid and dotted lines in Figures 4 and 5, the prevalence of paradoxical reactions was dependent on the definition. When using a ≥ 20% increase in NAR as the definition of a paradoxical reaction such a reaction was observed in five measurements (4.2%) for the baseline measurement I, in one measurement (1.8%) for follow-up measurement II, and in no measurement at measurement III. With a wider definition, that is, any increase in NAR, the prevalence was higher, 12 (10.1%) measurements in measurement I, nine (16.1%) measurements in measurement II, and nine (16.1%) measurements in measurement III. The paradoxical reactions to decongestant measured by NAR were not reflected in worsened nasal patency VAS scores.

As shown by the scatterplots (Figures 4 and 5) and data in Table 3, paradoxical reactions do not seem to be either bilateral or reproducible in either the long or short term, if the definition ≥20% increase in NAR is used as no subject would qualify. If any increase in NAR is regarded as a paradoxical reaction, one subject (3.6%) showed a long-term- and seven subjects (25%)a short-term reproducible paradoxical reaction. At baseline, the proportion of self-reported allergic rhinitis was lower, 18% (2/11), among subjects with paradoxical reactions to pharmacological decongestant compared to subjects without paradoxical reactions, 29% (14/49).

5.4 | Test–retest measurements and repeatability

At the time the follow-up measurements were conducted, 50 of the 60 subjects that participated in the baseline measurements had a follow-up time of ≥6 months. Of these 50, 30 still worked or studied at the hospital. Two subjects did not respond to the invitation and 28 subjects participated in the follow-up. The mean follow-up time was 12 months (SD 5), and the median follow-up time was 10 months (min–max 7–20).

No statistically significant differences ($p > .05$) were found between NAR values, for any of the sides, collected before decongestion at baseline (I) and at follow-up (II). Similarly, no statistically significant differences were found between ipsilateral NAR values collected after decongestion at baseline (I), at the first measurement at follow-up (II), or at the second measurement at follow-up (III) for any of the sides. The ICC and Cronbach's α were all >.75, except for the first and second NAR measurements on the right side before decongestion (Table 4).

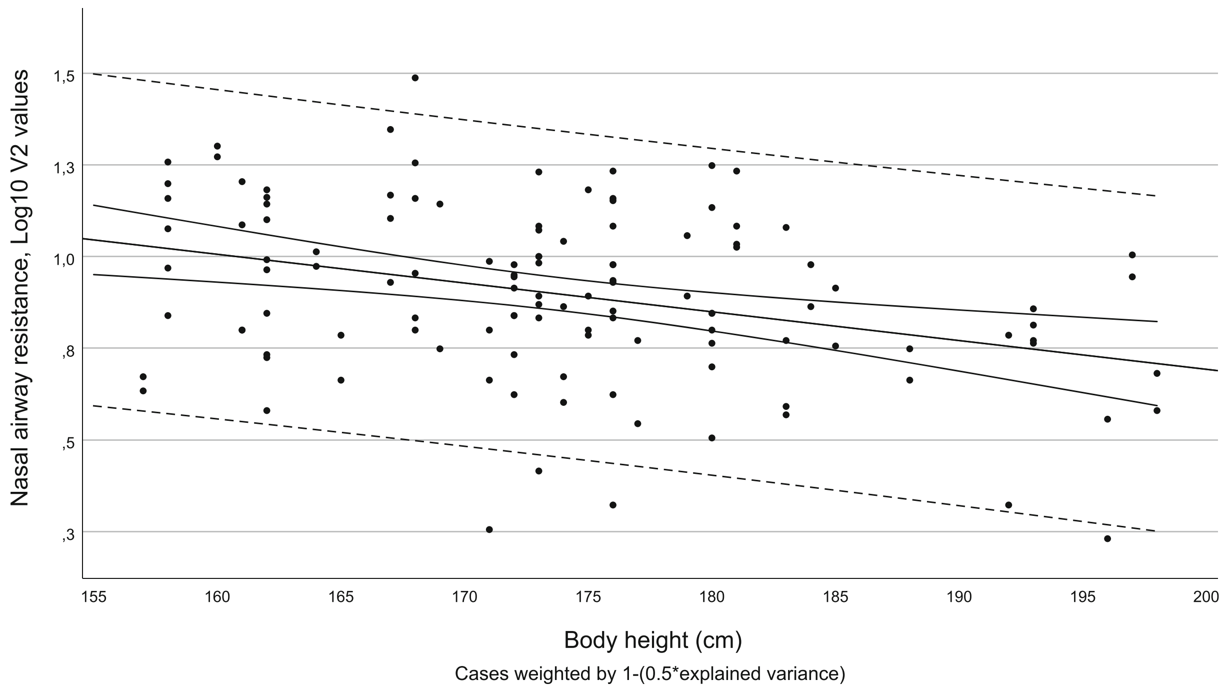


FIGURE 3 Nasal airway resistance (Log10V2) at baseline for the left- and right nasal cavity ($n = 120$) correlated to height. The regression line (solid line), 95% confidence intervals (dashed lines) and 95% prediction limits (dotted lines) are presented.

To establish the minimal difference between two measurements that with confidence signifies a true change, the SEMs for NAR values obtained after decongestion were calculated. The NAR SEM for long- and short-term repeatability was 0.11 and 0.09 in Log10 V2 values respectively.

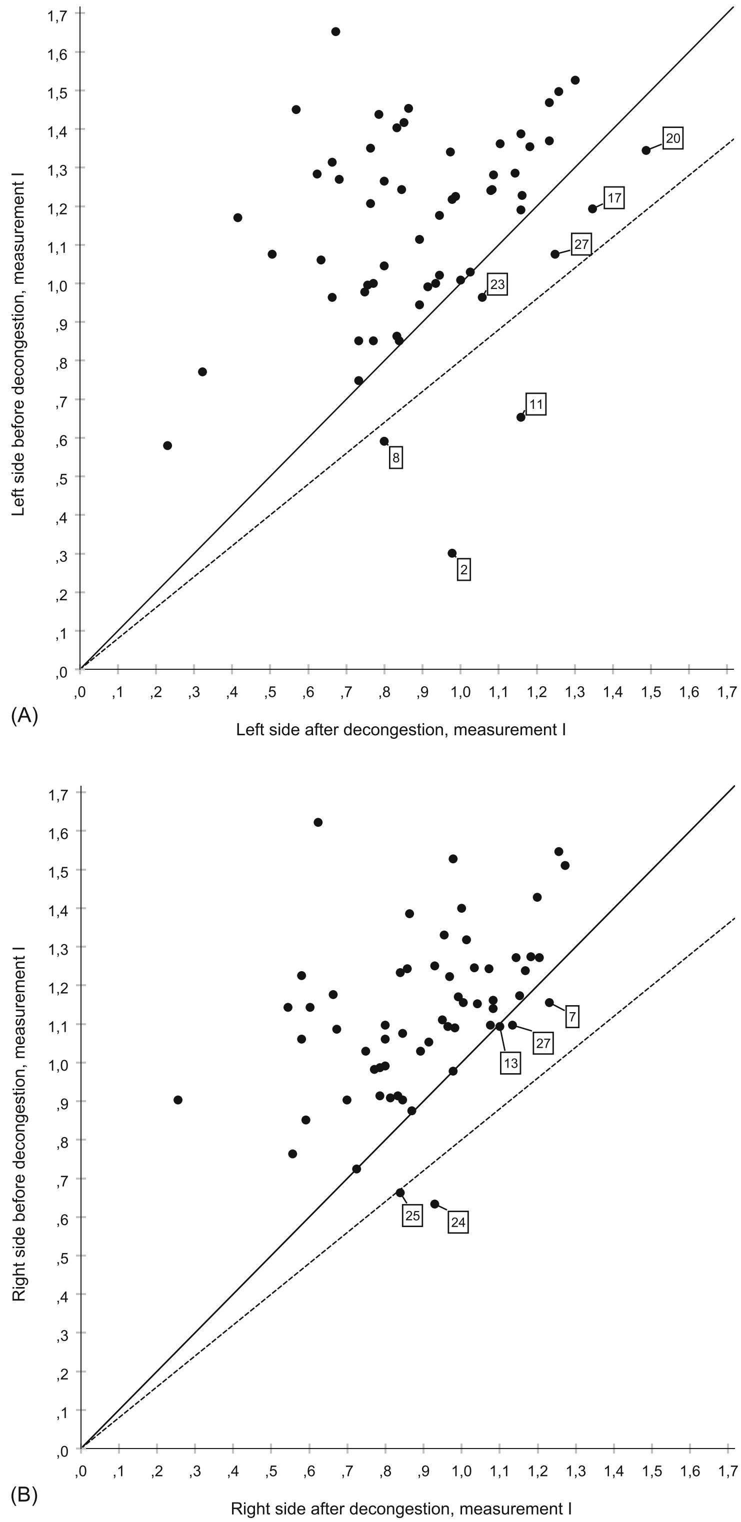
6 | DISCUSSION

6.1 | NAR values before and after decongestion

No statistically significant differences in NAR results were found between the right and the left sides of the nose or between males and females. This result applied to NAR values obtained both before and after decongestion and means that NAR values for the right and left sides and for males and females do not need to be analyzed separately in clinical practice and research. A finding from previous studies that we could corroborate was that NAR values obtained after decongestion were statistically significantly correlated to height.[6,19] However, the correlation to height (i.e., a stronger slope of the regression line) in our study was stronger than the correlations previously reported by both Broms et al. and Jessen et al. (Figure 6).

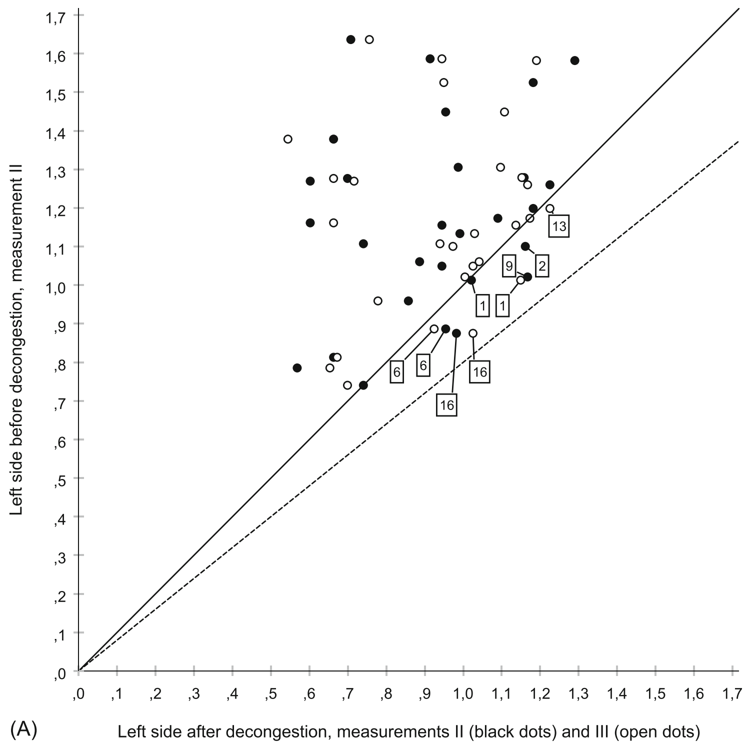
If AAR should be used to evaluate anatomical stenosis caused by deviated cartilage or bone it seems desirable to measure NAR on a maximally decongested nasal mucosa. As shown in the National Swedish survey (see "Introduction" section), a plethora of different methods for pharmacological decongestion is used in Swedish septoplasty operating units. We do not agree with the statement made by the Committee on standardization of AAR in 1984 that each rhinomanometrist should choose the way of decongestion that they prefer (i.e., imidazoline, adrenaline, exercise, etc.) as long as they mention it on the graph.[9] If each center uses its own mode for decongestion, comparison between centers is impossible. It is also likely that different types of decongestant, modes of administration, and the time given to achieve maximum effect yield different degrees of decongestion. In 1982, Broms et al. studied NAR with the Rhino-Comp® AAR and reported that physical exercise (bicycle ergometer to a pulse of 150 bpm) was more effective for decongesting the nasal mucosa than nose drops (oxymethazoline chloride, Nezeril®, 3 drops, 0,09 mL/0,045 mg in each cavity). This finding was contradicted by Jessen and Malm in 1988 who also studied NAR with the Rhino-Comp® AAR[19] using a combination of physical exercise and pharmacological decongestion with the conclusion that pharmacologic decongestion was more effective than physical exercise. A comparison of the efficacy of the three modes of decongestion used in the Broms et al. study, the Jessen et al. study, and our study is shown in Figure 6. The regression line based on the NAR measurements of our study is lower, that is, stronger decongestion, than the regression lines reported both by Broms et al. and Jessen et al. We, therefore, suggest that decongestion in NAR measurements with the Rhino-Comp® AAR should be obtained with the following procedure: two sprays of oxymetazoline hydrochloride 0.5 mg/mL in each nostril, a 15-min wait, another two sprays of oxymetazoline hydrochloride in each nostril, and a final wait of 5 min before measurement.

FIGURE 4 (A) and (B). Scatter plot with pre- and post-decongestion NAR values from measurement I. Left side $n = 59$ (A) and right side $n = 60$ (B). A dot below the solid line indicates an increased NAR after decongestion and a dot below the dotted line indicates a ≥ 20% increased NAR. For subjects with paradoxical reactions, subject numbers are presented to facilitate identification and comparisons between the left and right sides.

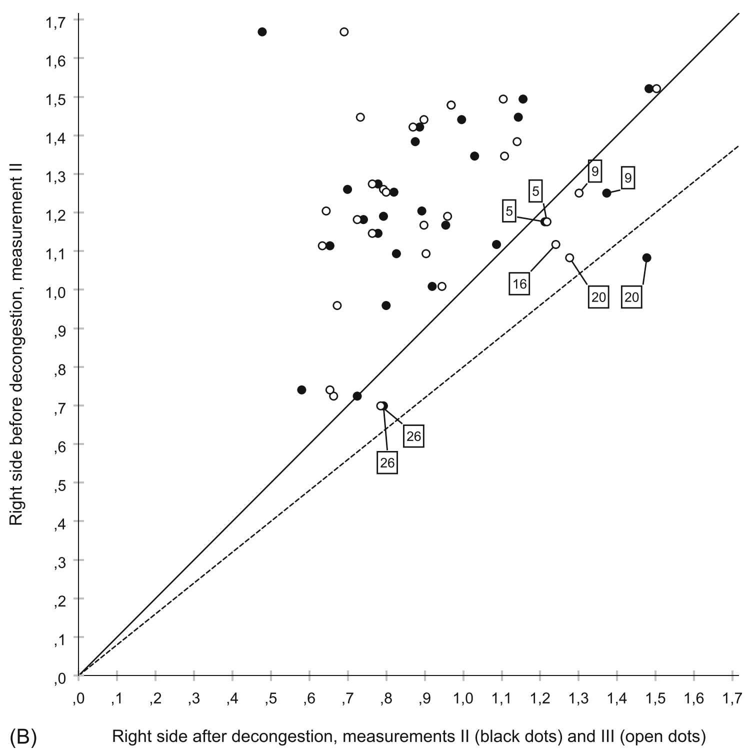


6.2 | Paradoxical reactions to pharmacological decongestion

The phenomenon of paradoxical reactions to pharmacological decongestion is well known to the clinician. It is, therefore, surprising that, to our knowledge, there is only one publication on the topic.[7] In the study by Swoboda et al. the Rhino-Comp® AAR was used and they chose to define a paradoxical reaction as an increase in NAR ≥20% based on the assumption that smaller increases were unreliable with normal or near normal NAR values. We agree with this assumption but a proportional definition such as the ≥20% definition is problematic as the requirements for what should count as a paradoxical reaction increase with increasing NAR values. The phenomenon is clearly shown in Figures 3 and 4 where the 20% line deviates more and more



(A)



(B)

FIGURE 5 A and B. Scatter plot with pre- and post-decongestion NAR values from measurements II and III. Left side (A) and right side (B). A dot below the solid line indicates an increased NAR after decongestion and a dot below the dotted line indicates a ≥ 20% increased NAR. For subjects with paradoxical reactions, subject numbers are presented to facilitate identification and comparison between the left and right sides and between measurements II and III.

from the zero change line as the NAR values get higher. With the ≥20% definition subjects with low NAR (e.g., tall subjects) are at a higher risk of having a NAR that will be classified as a paradoxical reaction.

Naturally, the prevalence of paradoxical reactions will be dependent on the definition. With the ≥20% definition, the prevalence was low (4.2%, 1.6%, and 0% in measurements I, II, and III, respectively) but fairly comparable to the findings of Swoboda et al. who reported a prevalence of 4.7%. With a wider definition (i.e., any increase in NAR) the prevalence was higher: 8.4% in measurement I and 16.1% in both measurements II and III.

When Swoboda et al. reassessed 36 of the subjects with a paradoxical reaction (≥20%) more than a decade from the first measurement, 33% had a same-sided paradoxical reaction. This is in contrast

TABLE 2 Characteristics of the decongestive effect of xylometazoline, that is, differences between Log10 V2 NAR values and nasal patency VAS scores obtained before and after decongestion.

	NAR left side			NAR right side			VAS left side		VAS right side	
	Measurement no			Measurement no			Measurement no		Measurement no	
	I	II	III	I	II	III	I	II	I	II
Number of subjects	59[a]	28	28	60	28	28	60	28	60	28
Mean	−0.24	−0.25	−0.23	−0.22	−0.28	−0.29	0.85	0.75	0.71	0.96
SD	0.30	0.28	0.29	0.22	0.30	0.28	1.1	0.0	1.0	0.5
Median	−0.23	−0.16	−0.13	−0.20	−0.32	−0.28	0.5	0	1	0.5
Minimum	−0.98	−0.93	−0.88	−1.0	−1.2	−1.0	−1	−2	−1	0
Maximum	0.68	0.15	0.15	0.30	0.39	0.19	4	4	4	6

Note: NAR obtained before decongestion are the same for measurements II and III.
[a]Due to a technical error the recording of the measurement before decongestion was lost.

TABLE 3 The difference in NAR obtained with and without decongestion, in subjects ($n = 17$) that had evidence of a paradoxical reaction to decongestion in any of the three measurements.

	Left side Measurement no			Right side Measurement no		
Subject no	I	II	III	I	II	III
1		0.01	0.14			
2	0.68*	0.06				
5					0.04	0.04
6		0.07	0.04			
7				0.08		
8	0.21*					
9		0.15			0.12	0.05
11	0.51*					
13			0.03	0.01		
16		0.11	0.15			0.12
17	0.15					
20	0.14				0.39*	0.19
23	0.09					
24				0.30*		
25				0.18*		
26					0.09	0.09
27	0.17			0.04		

Note: To facilitate interpretation, gray marking indicates a same-sided repeated increased NAR, while boxing indicates subjects with a bilateral increased NAR at the same measurement. Differences of ≥20% are marked with *.

to our study, where none of the subjects (0%) had a same-sided paradoxical reaction either at measurements I and II (long-term) or measurements II and III (short-term) with the ≥20% definition. If any increase in NAR should count as a paradoxical reaction, one subject (3.6%) had a reproducible long-term paradoxical reaction while seven (25%) subjects had a short-term same-sided reproducible paradoxical reaction. An interesting observation in our results was that bilateral paradoxical reactions were virtually absent since there was not a single case and only three cases with the ≥20% and the "any" increase definitions, respectively. We have no explanation for why the few subjects in our healthy population with mainly symmetrical NAR that showed signs of paradoxical reactions only showed the reaction on one side. All in all and at this point, we advise against using a proportional criterion such as ≥20% to define a paradoxical reaction. We suggest instead a fixed increase in NAR, but more studies on both healthy and obstructed noses are needed to decide the appropriate fixed value. However, it is possible that paradoxical reactions to pharmacological decongestants may lack clinical significance. We base this opinion on what we consider to be a low prevalence, a small magnitude of reaction, and a low reproducibility of paradoxical reactions to pharmacological decongestants in this study.

Furthermore, the presence of allergic rhinitis did not seem to be related to paradoxical reactions as the prevalence of allergic rhinitis in the group with paradoxical reactions was lower than in the group without paradoxical reactions.

6.3 | Repeatability and test–retest reliability

An often overlooked aspect of medical tests is repeatability, that is, the minimal change between two measurements that with confidence signifies a true change. This is especially important for AAR if it is to be used to evaluate the effect of septoplasty. The present study is the first to evaluate this aspect of the Rhino-Comp® AAR NAR values with a clinically relevant design and an appropriate statistical test. We found that the minimal change in NAR (Log10V2 values) that with confidence signifies a true change was 0.11 if minutes separated two measurements, and 0.09 if ≥6 months separated two measurements.

There are at least two previous publications where the Rhino-Comp® AAR has been used to evaluate reproducibility. In 1982, Broms[6] studied the reproducibility with the Rhino-Comp®AAR (1 week between measurements, decongestion with both pharmacological and physical exercise) with the conclusion that the

TABLE 4 Intra class coefficients (*r*) and Cronbach's α (measurements I vs. II $n = 56$, measurements II vs. III $n = 28$).

NAR variables			Confidence intervals		
		r	Lower	Upper	Cronbach's α
Before decongestion					
Measurements I-II	Left side	0.753	0.471	0.885	0.753
Measurements I-II	Right side	0.609	0.174	0.817	0.616
After decongestion					
Measurements I-II	Left side	0.803	0.579	0.909	0.814
Measurements II-III	Left side	0.921	0.831	0.963	0.920
Measurements I-II-III	Left side	0.890	0.795	0.945	0.893
Measurements I-II	Right side	0.791	0.552	0.903	0.790
Measurements II-III	Right side	0.917	0.820	0.961	0.914
Measurements I-II-III	Right side	0.887	0.789	0.944	0.886

Note: Average measures reported.

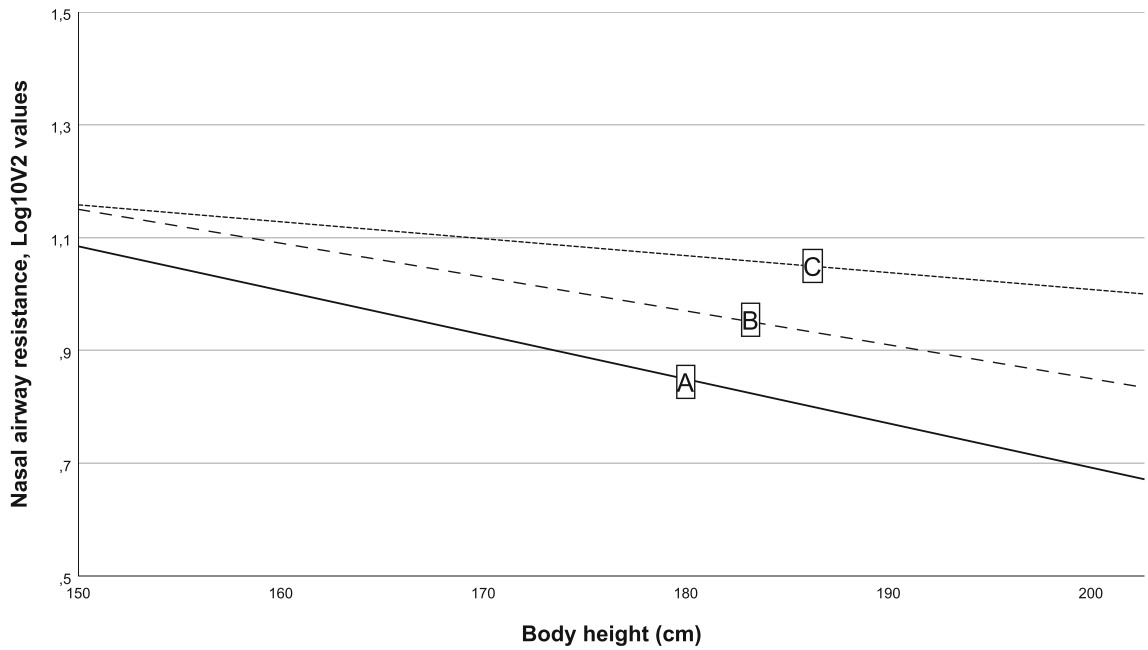


FIGURE 6 A comparison of NAR versus height regression lines from different studies using the Rhino-Comp® AAR. (A) The regression line from this study, $y = 2.26 - 0.00784 \times$ body height. (B) The regression line reported by Broms,[6] $y = 2.054 - 0.0061 \times$ body height. (C) The regression line reported by Jessen and Malm,[19] $y = 1.608 - 0.003 \times$ body height.

reproducibility was good. Thulesius et al. used a mean coefficient of variation to evaluate short-term (10 tests within an hour, five participants) and long-term reproducibility (10–15 measurements every 2–3 weeks, nine participants) with the conclusion that short-term variability was acceptable while long-term variability was not.[20] However, due to different designs and statistical tests the results from these two studies cannot be meaningfully compared to our results.

6.4 | Strengths and limitations

The single center/single measurer design can be both a strength and a limitation. The strength would be that all measurements were made in the same way with the same equipment. A limitation could be that the results are not generalizable. Another limitation was that we did not perform rhinoscopy. This means that some of the subjects might have had a non-symptomatic septal deviation or nasal polyposis even though the results on the S-NOSE, SNOT-22, and Nasal patency VAS scores strongly oppose this.

It must also be remembered that different types of AAR have different characteristics and our results may not be transferable to other devices, that is, other AAR devices than the Rhino-Comp®.

6.5 | Future studies

Our findings need to be corroborated in a multi-center study with a larger population including both healthy subjects and subjects with different degrees of nasal septum deviations. Furthermore, intra- and inter-rater studies of Rhino-Comp® AAR measurements are needed. Paradoxical reactions to pharmacologic decongestion also need to be further studied so that an appropriate characterization and definition of the reaction can be established. Correlations between subjective assessments of nasal function and AAR data both before and after surgery in septoplasty patients, as well as the effect of septoplasty on AAR results, need to be studied before any evidence-based guidelines for the use of AAR in clinical practice can be made.

6.6 | Conclusion

AAR NAR values were related to height but not to not sex or side, findings that must be taken into consideration when AAR is used in clinical practice. Our method of pharmacological decongestion seems to be superior to methods used in previous studies and we recommend that our method should be used in future studies as well as clinical practice. For the first time, the minimal difference between two measurements that with confidence signifies a true change was established, a finding with great importance for the evaluation of the outcome of septal surgery. Paradoxical reactions to pharmacological decongestion exist but the best definition remains to be decided and the clinical significance of paradoxical reactions needs to be further studied, especially in subjects with nasal stenosis.

ACKNOWLEDGMENT

The SNOT 22 was used under a license agreement with Washington University, USA

FUNDING INFORMATION

This study was funded by grants from Futurum- The Academy of Health and Care in Region Jönköping County, Sweden (FUTURUM- 803421).

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

Ola Sunnergren https://orcid.org/0000-0002-1192-0182

REFERENCES

1. Rimmer J, Hellings P, Lund VJ, et al. European position paper on diagnostic tools in rhinology. *Rhinology*. 2019;57(Suppl S28):1-41.
2. The Swedish Septoplasty Register. Public statistics page. https://sep.registercentrum.se In Swedish. Accessed May 19, 2023
3. Sunnergren O, Holmström M. Rinomanometri—Hur gör vi runt om i landet? Hur kan vi bli bättre? *Svensk ÖNH-Tidskrift*. 2022;30(3):6-8. In Swedish.
4. Broms P, Jonson B, Lamm CJ, Rhinomanometry II. A system for numerical description of nasal airway resistance. *Acta Otolaryngol*. 1982;94(1–2):157-168.
5. Clement PA, Gordts F. Standardisation committee on objective assessment of the nasal airway, IRS, and ERS. Consensus report on acoustic rhinometry and rhinomanometry. *Rhinology*. 2005;43(3):169-179.
6. Rhinomanometry BP III. Procedures and criteria for distinction between skeletal stenosis and mucosal swelling. *Acta Otolaryngol*. 1982;94(3–4):361-370.
7. Swoboda S, Thulesius HL, Jessen M. Paradoxical increase in nasal airway resistance after topical nasal decongestion—does it really exist? A retro- and prospective study. *Clin Otolaryngol*. 2016;41(6):689-693.
8. Broms P. Rhinomanometry. Thesis. Malmö 1980 90p.
9. Clement PA. Committee report on standardization of rhinomanometry. *Rhinology*. 1984;22(3):151-155.
10. Sunnergren O, Pakpour AH, Bergquist H, Sahlstrand-Johnson P, Stjärne P, Broström A. Validation and psychometric evaluation of the Swedish version of the nasal obstruction symptom evaluation scale. *Laryngoscope Investig Otolaryngol*. 2023;8(2):357-366.
11. Sahlstrand-Johnson P, Ohlsson B, von Buchwald C, Jannert M, Ahlner-Elmqvist M. A multi-centre study on quality of life and absenteeism in patients with CRS referred for endoscopic surgery. *Rhinology*. 2011;49(4):420-428.
12. IBM Corp. *IBM SPSS Statistics for Windows, Version 27.0*. IBM Corp; 2020.
13. Pallant J. *SPSS Survival Manual: A Step by Step Guide to Data Analysis Using IBM SPSS*. Open University Press, McGraw-Hill; 2016:335p.
14. Mishra P, Pandey CM, Singh U, Gupta A, Sahu C, Keshri A. Descriptive statistics and normality tests for statistical data. *Ann Card Anaesth*. 2019;22(1):67-72.
15. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Lawrence Erlbaum Associates; 1988:567p.
16. Field A. *Discovering Statistics Using IBM SPSS Statistics*. 3rd ed. SAGE Publications; 2013:916p.
17. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res*. 2005;19(1):231-240.
18. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med*. 2016;15(2):155-163.
19. Jessen M, Malm L. Use of pharmacologic decongestion in the generation of rhinomanometric norms for the nasal airway. *Am J Otolaryngol*. 1988;9(6):336-340.
20. Thulesius HL, Cervin A, Jessen M. Can we always trust rhinomanometry? *Rhinology*. 2011;49(1):46-52.

How to cite this article: Sunnergren O, Ahonen H, Holmström M, Broström A. Active anterior rhinomanometry: A study on nasal airway resistance, paradoxical reactions to decongestion, and repeatability in healthy subjects. *Laryngoscope Investigative Otolaryngology*. 2023;8(5):1136-1145. doi:10.1002/lio2.1157