

Alícia Graziela Noronha Silva Salgueiro¹
 Andressa Sharllene Carneiro da Silva¹
 Bruna Mara Adorno Marmontel Araújo¹
 Renata Paciello Yamashita¹
 Inge Elly Kiemle Trindade^{1,2}

Keywords

Speech
 Cleft Palate
 Velopharyngeal Insufficiency
 Acoustic Rhinometry
 Rhinomanometry

Descritores

Fala
 Fissura Palatina
 Insuficiência Velofaríngea
 Rinometria Acústica
 Rinomanometria

Correspondence address:

Inge Elly Kiemle Trindade
 Alameda Doutor Octávio Pinheiro
 Brisola, 9-75, Vila Universitária, Bauru
 (SP), Brasil, CEP: 17012-901.
 E-mail: ingetrin@usp.br

Received: 01/19/2015

Accepted: 03/12/2015

CoDAS 2015;27(5):464-71

Comparative analysis of velopharyngeal activity assessed by acoustic rhinometry and rhinomanometry

Análise comparativa da atividade velofaríngea aferida por rinometria acústica e rinomanometria

ABSTRACT

Purpose: To analyze the velopharyngeal (VP) activity of subjects with velopharyngeal dysfunction (VPD) by acoustic rhinometry, as compared to rhinomanometry. **Methods:** This was a prospective clinical study conducted in 41 adults, both genders, with repaired cleft palate, with or without a previously repaired cleft lip, and residual VPD on clinical assessment, without compensatory articulations for [p], [t], and [k]. The outcome measures were as follows: (1) on acoustic rhinometry, nasopharyngeal volumetric change (ΔV) during [p], [t], and [k], relatively to rest condition (decreases by $<3 \text{ cm}^3$ considered as absence of VP activity); (2) on modified anterior rhinomanometry, VP orifice area (areas $\geq 0.05 \text{ cm}^2$ considered as inadequate closure). The plosive [p] was used when comparing the techniques ($n=24$). **Results:** (1) A mean ΔV decrease of 18% was observed during [k], which was significantly lower ($p<0.05$) than the decrease reported for individuals without VPD (30%). ΔV values suggesting VPD were observed in 59% subjects. Similar results were obtained for [p] and [t], which shall be used as stimulus, given that they do not involve the use of the tongue to lift the velum during VP closure, differently from the velar plosive [k]. (2) Inadequate closure was seen in 85% subjects. No correlation was observed between ΔV and VP orifice area. Agreement between techniques was observed in 51% cases. **Conclusion:** Acoustic rhinometry had low accuracy as a diagnostic method of VPD when compared to the gold standard method. Nevertheless, the technique shows potential as a method for monitoring the outcomes of clinical and surgical treatment of VPD aimed at increasing velar and pharyngeal activity.

RESUMO

Objetivo: Analisar a atividade velofaríngea (VF) de indivíduos com disfunção velofaríngea (DVF) aferida por rinometria acústica, comparativamente à rinomanometria. **Métodos:** Estudo clínico prospectivo em 41 adultos, de ambos os gêneros, com fissura de palato+láblio previamente operada e DVF residual ao exame clínico, sem articulação compensatória nas plosivas surdas [p], [t] e [k]. Variáveis analisadas: (1) variação volumétrica da nasofaringe (ΔV) na produção das três plosivas, relativamente ao repouso, por rinometria acústica (reduções $<3 \text{ cm}^3$ foram consideradas como ausência de atividade velofaríngea); (2) área do orifício velofaríngeo (área VF), por rinomanometria anterior modificada; áreas $\geq 0,05 \text{ cm}^2$ foram consideradas como fechamento inadequado. Na comparação das técnicas foi utilizada a plosiva [p] ($n=24$). **Resultados:** Observou-se: (1) ΔV médio de 18% no [k], significativamente menor ($p<0,05$) que a redução relatada para normais (30%); valores de ΔV sugestivos de DVF constatados em 59% dos casos. Resultados similares foram obtidos no [p] e [t], mostrando-se mais apropriados para o exame rinométrico, por não envolverem a participação da língua no fechamento velofaríngeo, diferentemente da plosiva velar [k]; (2) fechamento VF inadequado em 85% dos casos. Não houve correlação significativa entre o ΔV e a área do orifício velofaríngeo. A concordância de diagnóstico entre os métodos ocorreu em 51% dos casos. **Conclusão:** A rinometria acústica não apresentou boa acurácia como método de diagnóstico da DVF frente ao método padrão. Demonstrou, contudo, potencial como método de acompanhamento dos resultados de intervenções clínico-cirúrgicas que levem à maior atividade velar e faríngea.

Study carried out at the Laboratory of Physiology of the Hospital for Rehabilitation of Craniofacial Anomalies, Universidade de São Paulo – USP – Bauru (SP), Brazil.

(1) Laboratory of Physiology, Hospital for Rehabilitation of Craniofacial Anomalies, Universidade de São Paulo – USP – Bauru (SP), Brazil.

(2) Department of Biological Sciences, Bauru School of Dentistry, Universidade de São Paulo – USP – Bauru (SP), Brazil.

Financial support: Fundação de Amparo à Pesquisa do Estado de São Paulo – FAPESP.

Conflict of interests: nothing to declare.

INTRODUCTION

Failure to achieve velopharyngeal closure in the production of oral sounds is generically designated as velopharyngeal dysfunction (VPD), which has significant effect on the resonance and other aspects of speech and may lead to hypernasality, nasal air emission, low intraoral pressure, and compensatory articulations^(1,2).

The auditory-perceptual assessment is the first approach to estimate signs and symptoms of VPD⁽²⁻⁴⁾. The use of rating scales⁽⁴⁻⁶⁾ and the audio and video recording of speech samples, with evaluation by judges, have been successful strategies to minimize the inherent subjectivity in this type of evaluation^(7,8). However, there is consensus that the subjective evaluation of VPD should be complemented with instrumental methods such as nasopharyngoscopy, videofluoroscopy, nasometry, and rhinomanometry. The latter, also known as pressure-flow technique, assesses the aerodynamic aspects of velopharyngeal activity, that is, the functional state of velopharyngeal mechanism, providing quantitative data contributing to the evaluation of therapeutic results⁽⁹⁻¹¹⁾.

In addition to these instrumental reference methods, another method proposed in the literature to assess velopharyngeal activity is acoustic rhinometry^(12,13). Sondhi and Gopinath⁽¹⁴⁾ introduced this method to assess nasal geometry. This technique allows consecutive measurements of the cross-sectional area and volume of different segments of nasal cavity, from the nostrils to the nasopharynx. Thereby it helps to identify the exact location of the constrictions that contribute to nasal resistance, in a quick, noninvasive manner and without any active participation of the patient⁽¹⁵⁾.

A study developed at the Laboratory of Physiology of the Hospital for Rehabilitation of Craniofacial Anomalies, in Bauru, São Paulo (HRAC/USP)⁽⁶⁾ confirmed, by analyzing the volume variation of nasopharynx in the production of the voiceless plosive [k], that the acoustic rhinometry was able to identify the deficit of velar movement featuring VPD in most patients clinically diagnosed with inadequate velopharyngeal function. However, some patients presented results suggesting good velar mobility on rhinometry, despite the VPD.

Therefore, as part of a series of studies that have been developed at the Laboratory of Physiology of HRAC/USP to study the efficiency and applications of acoustic rhinometry in the characterization of dysfunctions of velopharyngeal mechanism, this study compared the findings of acoustic rhinometry with another instrumental method already established in the literature — rhinomanometry⁽¹⁶⁾. A change in the conventional technique allows to estimate the cross-sectional area of the velopharyngeal orifice during speech and thereby classify the degree of velopharyngeal closure, based on the hydrokinetic principle that the area of an orifice can be measured knowing the difference of pressure between the sides of the orifice and the airflow through it^(9,17-20).

METHOD

The study was approved by the Research Ethics Committee in Human Beings of the HRAC/USP (CAAE 16540513.5.0000.5441),

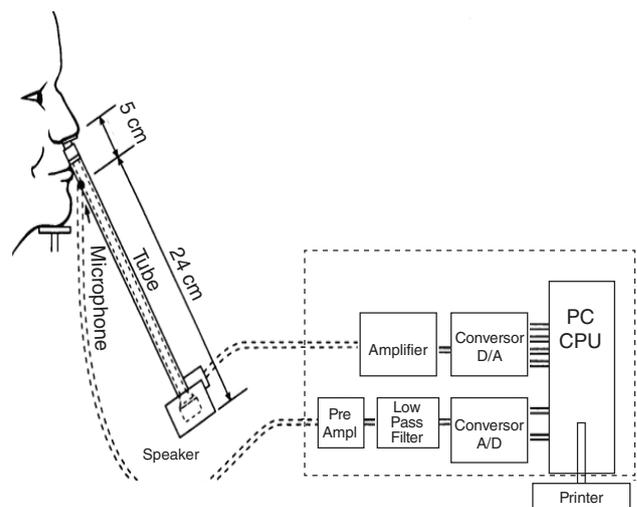
and the examinations were carried out after the participants or their guardians signed the informed consent.

The study was prospectively conducted at the Laboratory of Physiology of the HRAC/USP. We evaluated 41 individuals with cleft palate, with or without a previously repaired cleft lip, being 21 men and 20 women, aged between 12 and 39 years (22 ± 8 years on average).

For the selection of patients, we analyzed the results of auditory-perceptual evaluation of speech, routinely performed in the Laboratory of Physiology by experienced speech language pathologists^(1,4,20). The findings were not used for other purposes except the identification of patients eligible for the study.

Patients with compensatory articulation in the production of phone [p] and in the production of phones [p], [t], and [k] simultaneously were not included in the study, and also individuals with residual fistulas on the palate and/or pharyngeal flap, with obvious syndromes and signs or symptoms of nasal obstruction, hearing or physical/mental disability, which could compromise the exams.

The rhinometry assessment was performed in all 41 participants using an Eccovision Acoustic Rhinometer (HOOD Laboratories) and the methodology used by Trindade et al.⁽⁶⁾. The technique is based on the measurement of the reflected sound waves (echoes) that emerge from the nasal cavity in response to incident sound waves. It is conducted as follows: the proximal end of a tube, covered by a silicon piece (nose-piece) is leaned in one nostril; a sound wave generated by a loudspeaker propagates through the tube, passes a microphone, which is inactive at the moment, and enters the nasal cavity. Variations in the cross-sectional area, that is, any constraints that reduce the internal diameter of the cavity, cause the reflection of sound waves back into the rhinometry tube. Pressure signals sensitize the microphone, now active, and are amplified and digitized. A computer running specific software is used to analyze the signals (Figure 1, adapted from Roithmann et al.⁽²¹⁾). The cross-sectional area of the different nasal segments, from the nostril to the nasopharynx, is



Source: adapted from Roithmann et al.⁽²¹⁾

Figure 1. Acoustic rhinometer: instrumentation for the measurement of volumetric dimensions of the nasopharynx

calculated from the echo intensity. The distance of the segments with respect to the nostril is calculated from the wave speed and the echo arrival time. The data are converted into area–distance function and presented on a computer screen in the form of a graphic, the rhinogram, in which the area (in cm^2) is shown in semilogarithmic scale on the y-axis and the distance (in cm) on the x-axis. The system makes measurements in rapid succession in each test (10 sound pulses are generated approximately every 0.5 seconds) and the software calculates the average of the sectional areas and volumes of 10 repetitions.

The examination was performed in two stages; the first reproduces a situation of relaxation of the soft palate (rest) and the second, maximum velopharyngeal activity (speech). Step 1 (rest): once having the rhinometry tube positioned, and after some respiratory cycles of rest, the patient was requested to voluntarily suspend the breath at the end of exhalation and the system was activated for data acquisition. Three replicates were used for each nasal cavity, and the side with the best patency was chosen to analyze the nasopharyngeal volume, that is, the one with the highest average of the nasal valve cross-sectional area measured at the second deflection of the rhinogram. Step 2 (activity): the patient was asked to produce the syllable /ka/, keeping the intraoral pressure of the phone [k] for about 5 seconds until the end of data acquisition. The same was repeated for syllables /pa/ and /ta/. The equipment was calibrated at each period of the day and care was taken to minimize possible errors in the measurements⁽²²⁾.

The nasopharyngeal volume at rest (V_r) and during speech activity (V_k or V_p or V_t) was determined by integrating the area–distance curve, from the point of divergence between the rest and speech curves, corresponding to the region of choanas (or posterior border of the hard palate), up to 5 cm from that point. In the cases where the point of divergence was not clearly observed between the curves due to lack of velar mobility, the average distance observed in normal individuals as a starting point was adopted, corresponding to 7.7 cm from the nostrils, analyzing in both cases a 5-cm segment from the choanas corresponding to the nasopharynx.

The volumetric variation of the pharynx (ΔV) was determined by calculating the modulus of difference between the nasopharyngeal volume during production of the voiceless plosive [k] (V_k) and nasopharyngeal volume at velar rest (V_r), that is, $|V_k - V_r|$, which is the absolute difference (ΔV_A). The ratio $|V_k - V_r| / V_r$ was also determined, which corresponds to the relative difference (ΔV_R). The same was repeated for the voiceless plosives [p] and [t]. The analysis of the difference between two successive volumetric measurements in the same individual eliminates factors that may interfere with measurements made at the posterior portion of the nasal cavity.

All participants also underwent modified anterior rhinomanometry (pressure-flow technique) using a computerized system PERCI-SARS (version 4.01; Microtronics Corp.). The data were compared with the results of acoustic rhinometry. The technique allows the measurement of the area of the velopharyngeal orifice by the simultaneous measurement of differential pressure between the two sides of

a constriction and the airflow during the production of the phone, which requires maximum velopharyngeal activity, usually a plosive. A catheter is positioned within the oral cavity and another in the nostril with lower nasal flow, which is held in position by a cork (olive); both measure static air pressure, which is transmitted to pressure transducers. The nasal airflow is measured through a plastic tube adapted to the nostril of higher, which is connected to a heated pneumotachograph with a pressure transducer. The signals from the three transducers (nasal pressure, oral pressure, and nasal flow) are sent to PERCI system for analysis by a specific software (Figure 2). The system was calibrated once a week with known signals of flow (250 mL/s) and pressure (6 cm H_2O) using a flowmeter and a water manometer, respectively.

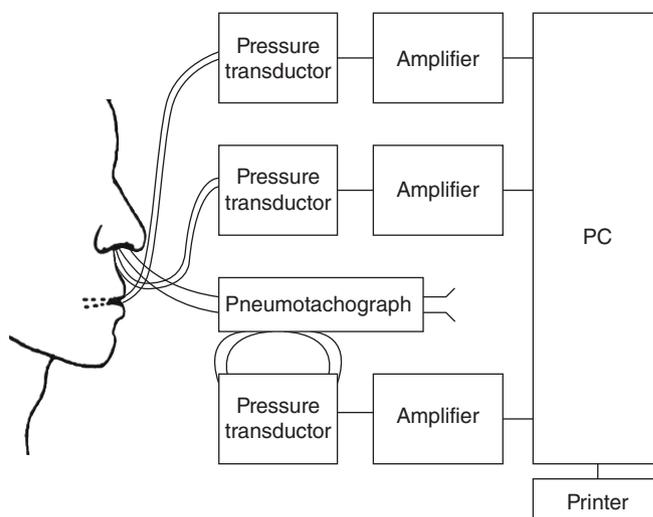


Figure 2. Modified anterior rhinomanometry: instrumentation for measuring the area of velopharyngeal orifice⁽⁹⁾

For the purposes of this study, we analyzed the area of the velopharyngeal orifice during production of the voiceless plosive [p] inserted in the word “rampa,” and evaluated four to six successive emissions of each production per individual. The area considered for analysis represents the average of these multiple productions and is calculated by the program, from the equation: $A = F/k (2 \Delta P/d)^{1/2}$, where A =orifice area in cm^2 , F =nasal flow in ml/s, $k=0.65$, ΔP = difference between oral and nasal pressure in cm H_2O , and d =air density in g/cm^3 . As previously mentioned, patients with compensatory articulation in the production of the phone [p] were not included in the study.

The velopharyngeal closure was categorized according to the velopharyngeal area observed: areas $<0.05 \text{ cm}^2$ = adequate closure; 0.05 to 0.19 cm^2 = marginal closure; and $\geq 0.20 \text{ cm}^2$ = inadequate closure (modified from Warren⁽²³⁾). To analyze the accuracy of rhinometry, we considered areas $\geq 0.05 \text{ cm}^2$ as indicative of inadequate closure.

Data analysis

In regard to the acoustic rhinometry, considering that the variable volume follows a normal distribution, with only a slight deviation to the left⁽²⁴⁾, the results for nasopharyngeal volumes at rest and during speech were expressed as mean±standard deviation. For the purposes of this study, we used $\Delta V=3\text{ cm}^3$ as the normal limit, that is, values below this limit ($\Delta V<3\text{ cm}^3$) were interpreted as indicative of inadequate velopharyngeal activity⁽⁶⁾.

The significance of differences between the nasopharyngeal volumes observed in both conditions studied (rest and velopharyngeal activity) was analyzed using Student's *t*-test for related samples and observed among groups by Student's *t*-test for independent samples. The significance of difference between more than two groups ($\Delta V<3\text{ cm}^3$, $\Delta V\geq 3\text{ cm}^3$, and control) was investigated by analysis of variance (ANOVA) and, when found significant differences, the Tukey test was used. The volume variation of the nasopharynx (ΔV) and the cross-sectional area of the velopharyngeal orifice were compared by ANOVA and, when found significant, and, when found significant differences, the Tukey test was used. In all tests, $p<0.05$ was adopted as significance level.

RESULTS

All patients included in the study presented VPD in clinical diagnosis, and 59% (24/41) were considered to have marginal velopharyngeal function, and the remaining 41% (17/41) inadequate velopharyngeal function. None showed compensatory articulation in the voiceless plosive [p], 27 showed no compensatory articulation in [k], and 33 in [t]. Adequate articulation of the three plosives, simultaneously, was observed in 24 patients.

Acoustic rhinometry

Analysis of the average values of the nasopharyngeal volume

Table 1 shows the mean values of the nasopharyngeal volume at rest and in the production of [k] obtained in 27 subjects with VPD who showed adequate articulation for the plosive. At rest, an average volume of 20.1 cm^3 was observed, which did not significantly differ ($p=0.116$) from the one reported by Trindade et al.⁽⁶⁾ in normal individuals (without VPD), indicating equivalent nasopharyngeal dimensions. In the group with VPD, the average volume decreased to 17.4 cm^3 during speech, corresponding to an average reduction of 3.9 cm^3 in absolute terms, and 18% in relative values. The values obtained at rest and during speech, although close, differed significantly ($p=0.005$), as Trindade et al.⁽⁶⁾ showed for control subjects, but the reduction was significantly lower in the group with VPD, here studied, indicating less velopharyngeal activity.

Table 1. Mean nasopharyngeal volumes obtained at rest and during speech activity in subjects with velopharyngeal dysfunction compared to those observed by Trindade et al.⁽⁶⁾ in individuals without VPD, with equivalent age. Below are mean (\pm SD), minimum and maximum values, and absolute and relative variation, expressed as a module

	Volumes (cm^3) in production of [k]			
	Group with VPD (n=27)		Group without VPD (n=18)	
	Mean±SD	Min–Max	Mean±SD	Min–Max
Rest (Vr)	20.1±6.4	10.7–32.5	23.2±6.4	14.6–35.1
Speech (Vk)	17.4±6.4**	10.1–36.1	15.9±3.8**	9.4–21.7
Absolute variation ΔV	3.9±3.5	0.2–10.8	7.3±4.2*	3.1–18.9
Relative variation ΔVR %	18±14%	1.6–44.1	30±10%*	14.2–3.8

* $p<0.05$ statistically significant difference (VPD versus no VPD) – *t*-test; ** $p<0.05$ statistically significant difference (rest versus speech) – paired *t*-test

Caption: Vr = volume at rest; Vk = volume during production of phone [k]; | ΔV | = $V_k - V_r$; | ΔVR %| = $(V_k - V_r)/V_r$; SD = standard deviation; Min = minimum; Max = maximum; VPD = velopharyngeal dysfunction

Table 2 presents the results obtained in the production of [k] recalculated for 24 patients who had no compensatory articulation in the [p] and [t] simultaneously, and, for comparison purposes, results in the production of these two other plosives. The results did not statistically differ, both in relation to the average values of the nasopharyngeal volume at rest and during speech, as in relation to the absolute and relative volume variation, validating the measurement technique and the alternative use of the voiceless plosives [p] and [t].

Analysis of individual values of the nasopharyngeal volume

Considering the finding of similar results among the three investigated plosives and the subsequent comparison of the results of acoustic rhinometry with rhinomanometry, which makes use of the voiceless plosive [p], the following analysis is made in the production of this plosive.

Table 3 shows that in the production of the phone [p], 23 of the 41 (56%) patients with VPD showed no significant reduction in nasopharyngeal volume during speech activity ($\Delta V<3$), suggesting absent or inadequate velopharyngeal activity. On average, a reduction of 1.2 cm^3 (7%) was observed. However, in other 18 patients (44%), a significant decrease in nasopharyngeal volume ($\Delta V\geq 3$) was observed, suggesting the presence of velopharyngeal activity despite the diagnosis of VPD. In this case, the reduction was 6.9 cm^3 (31%). The values of the two subgroups significantly differ in rest ($p=0.004$), in the absolute variation ($p<0.001$) and in the relative variation ($p<0.001$). These data confirm previous observations of Trindade et al.⁽⁶⁾. It should be noted that the number of patients correctly identified as having inadequate velopharyngeal activity was similar for the two other voiceless plosives [k] and [t] (59% and 67%, respectively).

Modified anterior rhinomanometry

Analysis of velopharyngeal closure

All 41 patients who were examined by acoustic rhinometry also underwent modified anterior rhinomanometry to measure velopharyngeal orifice area. We observed areas ranging from 0.001 cm² — denoting total velopharyngeal closure, that is, no gap — to values equal to or greater than 0.20 cm², indicating absence of velopharyngeal closure, at least in the production of the plosive [p].

The proportion of cases in each closure category (adequate, marginal, and inadequate) is presented in Table 4, which shows that most patients (73%; 30/41) had inadequate closure (area ≥0.20 cm²), a result consistent with the clinical diagnosis. If added to these cases those five with corresponding area to the marginal category, the proportion rises to 85% (35/41). The remaining 15% (6/41) of the sample were categorized as adequate, despite the clinical diagnosis of VPD. The average velopharyngeal areas were found to differ between the three categories considered (p<0.001), reinforcing the diagnostic value of rhinomanometry.

Comparison with the acoustic rhinometry

Table 4 also shows that there was no relationship between the findings of rhinometry and rhinomanometry. That is because no significant differences were shown between the average volumetric variations observed in the subgroups with adequate, marginal, and inadequate FVF (p=0.800). Moreover, the statistical analysis confirmed the absence of correlation between the individual data obtained by both methods (r=0.14), as shown in Figure 3.

Table 5 shows the analysis of the diagnostic accuracy of acoustic rhinometry compared to the rhinomanometry data (standard method), using a 2x2 table. In rhinometry, |ΔVA|<3 was considered a positive result (inadequate velopharyngeal activity) and |ΔVA| ≥3 a negative result (adequate velopharyngeal activity). In rhinomanometry, a marginal or inadequate closure was considered a positive result, and adequate velopharyngeal closure as a negative result. In doing so, we found that there was agreement in the diagnosis of 21 patients, which corresponds to 51% cases.

Table 2. Mean nasopharyngeal volumes obtained at rest and in different speech activities ([k], [p], and [t]) in subjects with velopharyngeal dysfunction. Below are mean (±SD), minimum and maximum values, and absolute and relative variation, expressed as a module

	Volumes (cm ³)					
	Sample [p]		Sample [t]		Sample [k]	
	Mean±SD	Min–Max	Mean±SD	Min–Max	Mean±SD	Min–Max
Rest (Vr)	20.9±6.2	12.1–32.5	20.9±6.1	12.1–32.5	20.9±5.9	12.1–32.2
Speech (V)	18.1±6.4*	11.3–36.2	18.1±5.7*	10.7–31.7	18.4±5.6*	10.4–31.5
Absolute variation ΔVA	4.2±3.6	0.2–10.8	3.6±2.8	0.2–9.2	3.1±2.9	0.3–10.3
Relative variation VR%	18±14%	1.6–44.1	16±12%	1.6–40.9	14±12%	2.1–41.9

*p<0,05 statistically significant difference (rest versus speech) – paired t-test

Caption: Vr = volume at rest; V = volume during speech activity; |ΔVA| = V – Vr; |ΔVR%| = V – Vr/Vr; SD = standard deviation; Min = minimum; Max = maximum

Table 3. Mean nasopharyngeal volumes obtained at rest and during speech activity in subjects with velopharyngeal dysfunction, divided into two subgroups according to the volume variation observed (<3 and ≥3 cm³). Below are mean values (±SD), minimum and maximum values, and absolute and relative variation, expressed as a module

	Volumes (cm ³) in production of [p]			
	ΔVA <3 cm ³		ΔVA ≥3 cm ³	
	Mean±SD	Min–Max	Mean±SD	Min–Max
n (%)	23 (56)		18 (44)	
Rest (Vr)	17.8±5.8	11.6–32.3	24.9±7.12*	14.8–43.5
Speech (V)	17.1±5.7**	11.1–31.7	18.7±5.9**	9.9–28.8
Absolute variation ΔVA	1.2±0.9	0.0–2.9	6.9±3.2*	3.2–14.6
Relative variation VR%	7±5%	0.3–18.4	28±9*	12.4–40.9

*p<0.05 statistically significant difference (|ΔVA| <3 cm³ versus |ΔVA| ≥3 cm³) – ANOVA/Tukey test; **p<0.05 statistically significant difference (rest versus speech) – paired t-test

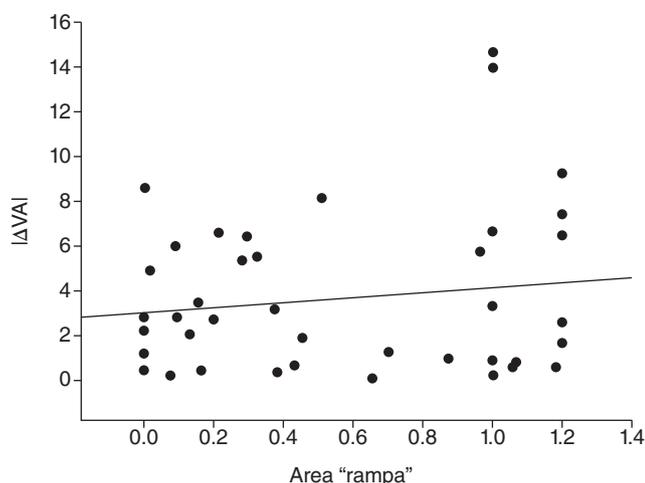
Caption: Vr = volume at rest; Vp = volume during production of phone [p]; |ΔVA| = Vp – Vr; |ΔVR%| = Vp – Vr/Vr; SD = standard deviation; Min = minimum; Max = maximum

Table 4. Absolute and relative variation of the nasopharyngeal volume in production of phone [p] in subjects with velopharyngeal dysfunction, expressed as a module according to the degree of velopharyngeal closure, measured in the production of phone [p], in the word “rampa”, categorized as adequate, marginal, and inadequate in the rhinomanometric examination

Velopharyngeal closure	n (%)	Rhinomanometry		
		Velopharyngeal area (cm ²)	Rhinometry Volumetric variation [p]	
			Mean±SD	Mean±SD
Adequate (A)	6 (15)	0.01±0.1	3.3±3.0	18.2±14.3%
Marginal (M)	5 (12)	0.11±0.03	2.8±2.1	13.2±10%
Inadequate (I)	30 (73)	0.77±0.37*#	3.9±4.0	16±13.3%

*p<0.05 statistically significant difference (velopharyngeal area I versus A) – ANOVA/Tukey test; #p<0.05 statistically significant difference (velopharyngeal area I versus M) – ANOVA/Tukey test

Caption: SD = standard deviation



r=0.14; p>0.050

Figure 3. Relationship between volume variation of the nasopharynx (Δ VAl) measured by acoustic rhinometry and area of velopharyngeal orifice ("rampa") measured by modified anterior rhinomanometry

Table 5. Distribution of individuals with velopharyngeal dysfunction according to velopharyngeal activity measured by acoustic rhinometry (volumetric variation of the pharynx), and rhinomanometry (velopharyngeal closure), in the production of phone [p]

Rhinometry (Volumetric variation)	Velopharyngeal activity		
	Rhinomanometry (velopharyngeal closure)		
	Marginal or Inadequate	Adequate	Total
$ \Delta$ VAl<3 cm ³ inadequate	19	4	23
$ \Delta$ VAl≥3 cm ³ adequate	16	2	18
Total	35	6	41

Caption: Δ VAl = volumetric variation

DISCUSSION

This research is part of a series of studies being carried out at the Laboratory of Physiology of HRAC/USP to analyze the applications of acoustic rhinometry as an assessment method of the activity of the velopharyngeal structures and its validity⁽⁶⁾.

In this study, we compared the findings of the acoustic rhinometry with data of the modified anterior rhinomanometry. Regarding the rhinometric technique itself, the findings were consistent with a previous study. Reinforcing an original proposal of Dalston⁽¹²⁾, it was proven, once again, that the technique can be used to identify deficiencies in velopharyngeal movement during speech. The average reduction in nasopharyngeal volume was of 18% in the patients with VPD presently studied, while the variation reported by Trindade et al.⁽⁶⁾ in normal individuals was considerably higher (30%). In absolute values, the variation in dimensions in of the nasopharynx in the speech of normal individuals corresponded to 7.3 cm³. At first glance

this value may seem small, but we must remember that it is a cubic size (cm³) and not quadratic (cm²), thus representing a significant tridimensional change.

Second, it was found, as in the previous study, that the acoustic rhinometry was not able to confirm the clinical diagnosis of impairment of velopharyngeal activity in all subjects analyzed, confirming the inconsistency between clinical and rhinometric diagnosis. Therefore, validating the technique against instrumental evaluations already established in the literature became necessary.

So far, no study has compared the findings of acoustic rhinometry with rhinomanometry, and a single study made a comparison to videofluoroscopy⁽¹³⁾. These authors studied the change in velar positioning during the production of a sustained and "silent" /f/ (with the velopharyngeal orifice closed) relatively to rest (with the velopharyngeal orifice open), investigating if the changes in the volume of the nasopharynx suggested by rhinometry matched the images displayed on videofluoroscopy. The study was conducted with two normal speakers (the authors themselves) and on videofluoroscopy, linear distance measurements were made along a line between the tip of the nose piece and the most anterior point where velar tissue was observed rising above the palatal plane and the most superior point on the nasal surface of the velum during velopharyngeal closure. And in rhinometry, the distance from the point of divergence of the rhinograms obtained at rest and in the production of the same speech sample over the same reference (5cm) was considered. They observed an excellent correlation between both measurements, with a difference of less than 1 cm from each other.

In this study, we used a similar methodology, except for one important difference: the speech samples used for analysis — the phones ([p], [t], and [k]), classified as occlusive, voiceless, and distinguished as bilabial, alveolar, and velar respectively, by manner of articulation. We avoided the isolated use of [k] because this plosive presents as articulators not only the soft palate but also the tongue, a variable not previously controlled. Nasopharyngeal volume was measured in the impounding phase of intraoral pressure, maintained by the patient for a few seconds. Preliminary data from an ongoing study using videofluoroscopy have shown the absence of participation of the tongue in velopharyngeal closure in all patients studied so far, which reduces the likelihood of such articulation in rhinometry. Independent of this finding, we decided to also use [t], to exclude the influence of tongue on the volumetric variation observed. Also, [p] was used for purposes of comparison with rhinomanometry, data for which this phone is a standard sample. At first, we also considered the possibility of including phone /f/, produced in a prolonged and quiet way, as proposed by Dalston⁽¹²⁾. But confirming preliminary observations, its use proved to be unfeasible due to the instability observed in the curves recorded during prolonged production of [f]. This instability was attributed to the friction of expiratory air in its passage through the oral vocal tract, typical of the fricative sound, and more pronounced in patients with VPD. Thus,

the evaluations made during the production of fricative [f] have been disregarded.

Statistical analysis showed that the average volume and the absolute and relative volume variation in the production of [p] and [t] did not differ from those observed for [k]. It is noteworthy that the number of patients correctly identified as having inadequate velopharyngeal activity was similar for the three plosives. Taken together, these observations validate the measurement technique and the combined or isolated use of these speech samples for the analysis of velopharyngeal activity, which, in patients with VPD, proves to be very useful, because of the articulation disorders that usually affect plosives.

Moreover, we also observed a high proportion of cases that showed noncompatible result with VPD on rhinometry, that is, volumetric variation that indicates good “velar and pharyngeal mobility” in the presence of clinically diagnosed VPD. This observation limits the value of acoustic rhinometry as a diagnostic method of VPD. However, Fukushiro et al.⁽²⁵⁾ showed differences in velopharyngeal closure in the production of syllables compared to sentences in patients with VPD. The authors found that a greater number of patients with repaired cleft lip and palate and VPD achieved adequate velopharyngeal closure on the emission of syllables than in the production of sentences. At least in part, this may be the explanation for the results obtained here because rhinomanometric examination is based on the production of single syllables. In addition among the 41 individuals included in the study, 59% were classified as having marginal velopharyngeal function, using the protocol proposed by Trindade et al.^(4,6). In marginal cases, velopharyngeal closure can be achieved in short emissions, such as syllables, from aerodynamic strategies such as increased breathing effort and thus intraoral pressure⁽²⁶⁾, which may have occurred on rhinometry.

The diagnostic accuracy of a test as the acoustic rhinometry to identify a “disease” as VPD requires the study of the relationship between the test result and the occurrence of the disease that needs to be identified, diagnosed by another test considered gold standard. In this study, we used the modified anterior rhinomanometry, which is a well-established method in the literature for measuring the cross-sectional area of the velopharyngeal orifice⁽¹⁹⁾. The technique has as advantage that it assesses the velopharyngeal mechanism in its functional aspect, and it is not invasive. The area is usually determined during the production of voiceless bilabial plosive [p] inserted in the word “hamper.” The sequence /mp/ allows to test the velopharyngeal functioning in continuous speech because it requires quick adjustments of the velopharyngeal structures, which go from rest in /m/ to maximum activity in [p]⁽⁹⁾. The exam showed that most patients (73%) were classified as having inadequate velopharyngeal function, showing better performance in identifying VPD than acoustic rhinometry, which best performance was able to identify VPD in 67% cases (phone [t]). It was also noted that the corresponding volume variation to the three categories diagnosed by rhinomanometry did not differ (adequate = 18% reduction; marginal = 13% reduction; inadequate = 16% reduction), and

there was no significant correlation between the individual results obtained by both methods, suggesting rhinomanometry has a better accuracy as a diagnostic method.

Considering that the accuracy of a test corresponds to the proportion of true positive and true negative cases in relation to the total results⁽²⁷⁾, to better analyze acoustic rhinometry performance, it was decided to adjust the classification of VPD in rhinomanometry to a dichotomous model, that is, present or absent VPD. Therefore, the “marginal” closure was included as “inadequate” in rating. Moreover, considering that in acoustic rhinometry, a positive result (presence of VPD) is the observation of a $|\Delta VA| < 3$ (inadequate velopharyngeal activity) and a negative result is a $|\Delta VA| \geq 3$ (adequate velopharyngeal activity) and, in rhinomanometry, a positive result is the observation of marginal and inadequate velopharyngeal closure, and a negative result is the adequate closure, low agreement was found among the methods (50%), which definitely shows low accuracy of rhinometry in identifying VPD. The low agreement between both techniques can be explained by factors related to the prolonged sound tested, prerequisite in acoustic rhinometry:

1. prolonged [p], which does not require much skill of the velopharyngeal mechanism as the sequence /mp/ used in rhinomanometry;
2. loss of sealing ability for deficiency in the contact force between the nasal surface of the soft palate and the posterior pharyngeal wall or muscle fatigue, which, as a matter of fact, explains the inconsistent closing at times observed⁽²⁸⁾; and/or
3. closure delay⁽²⁹⁾.

Another limitation to eventually explain the mismatch percentage found between the techniques concerns the fact that the tests were not conducted simultaneously. This means that inconsistent defects may have influenced measurements at different occasions. We could also question the type of speech sample used, as plosives in syllabic context do not reproduce spontaneous speech. However, this limitation is not exclusive of acoustic rhinometry, it also applies to rhinomanometry. What is restricted to rhinometry is the need to extend the articulatory gesture sound that initiate the syllable, in this case the plosives, which leads to a somewhat artificial production that may not represent the operation functioning of the velopharyngeal mechanism in normal conditions. As for other possible limitations, widely discussed in other publications of the Laboratory of Physiology of the HRAC/USP^(6,22,30), all were considered, in the context of a project that aims to contribute to the analysis of the feasibility of using a technique as a complementary method for assessing velopharyngeal function.

Considering that the sphincter action of the velopharynx comprises the superior and posterior movement of the soft palate, the medial movement of the lateral walls, and the anterior movement of the posterior pharyngeal wall, with individual variations in the participation of these components in the orifice closure, it is relevant to compare the rhinometric results with images of velopharyngeal structures

in activity, generated by nasopharyngoscopy and video-fluoroscopy. Faults of the velar activity and/or pharyngeal walls could explain the observations made up to this point. Ongoing studies are exploring these approaches.

CONCLUSION

From the results, we can observe, once again, the capacity of acoustic rhinometry in identifying individuals with VPD. However, the comparison with rhinomanometry showed that its accuracy as a diagnostic method is an unclarified question. In future studies, it is necessary to compare the technique with direct methods of VPD evaluation and test its applications in monitoring therapeutic, surgical, prosthetic interventions in which the patient is control of him/herself. Apparently, it is in this context that acoustic rhinometry can bring major contributions to the field of Speech Language Pathology.

**AGNSS participated in the idealization of the study, collection, analysis, and interpretation of data, and writing of the article; ASCS, BMAMA, and RPY participated in data collection; IEKT participated in the superior condition, in the idealization of the study, in the analysis, data interpretation, and writing of the article.*

REFERENCES

- Genaro KF, Yamashita RP, Trindade IEK. Avaliação clínica e instrumental da fala na fissura labiopalatina. In: Fernandes FDM, Mendes BCA, Navas ALPGP, editores. Tratado de fonoaudiologia. São Paulo: Roca; 2010. p. 488-503.
- Kummer AW, Clark SL, Redle EE, Thomsen LL, Billmire DA. Current practice in assessing and reporting speech outcomes of cleft palate and velopharyngeal surgery: a survey of cleft palate/craniofacial professionals. *Cleft Palate Craniofac J.* 2012;49(2):146-52.
- Kummer AW, Briggs M, Lee L. The relationship between the characteristics of speech and velopharyngeal gap size. *Cleft Palate Craniofac J.* 2003;40(6):590-6.
- Trindade IEK, Genaro KF, Yamashita RP, Miguel HC, Fukushiro AP. Proposta de classificação da função velofaríngea na avaliação perceptivo-auditiva da fala. *Pro-Fono R Atual Cient.* 2005;17(2):259-62.
- Abdel-Aziz M. Speech outcome after early repair of cleft soft palate using Furlow technique. *Int J Pediatr Otorhinolaryngol.* 2013;77(1):85-8.
- Trindade IE, Araújo BM, Teixeira AC, Silva AS, Trindade-Suedam IK. Velar activity in individuals with velopharyngeal insufficiency assessed by acoustic rhinometry. *J Appl Oral Sci.* 2014;22(4):323-30.
- Lohmander A, Willandsen E, Persson C, Henningsson G, Bowden M, Hutters B. Methodology for speech assessment in the Scandicleft Project: an international randomized clinical trial in palatal surgery experiences from a pilot study. *Cleft Palate Craniofac J.* 2009;46(4):347-62.
- Sweeney T. Nasality: assessment and intervention. In: Howard S, Lohmander A. *Cleft palate speech: assessment and intervention.* Malden: Wiley-Blackwell; 2011. p. 199-220.
- Trindade IEK, Yamashita RP, Gonçalves CGAB. Diagnóstico instrumental da disfunção velofaríngea. In: Trindade IEK, Silva Filho OG, organizadores. *Fissuras labiopalatinas: uma abordagem interdisciplinar.* São Paulo: Santos; 2007. p. 123-43.
- Hopper RA, Tse R, Smartt J, Swanson J, Kinter S. Cleft palate repair and velopharyngeal dysfunction. *Plast Reconstr Surg.* 2014;133(6):852e-64e.
- Kummer AW. Speech evaluation for patients with cleft palate. *Clin Plast Surg.* 2014;41(2):241-51.
- Dalston RM. Acoustic assessment of the nasal airway. *Cleft Palate Craniofac J.* 1992;29(6):520-6.
- Seaver EJ, Karnell MP, Gasparaitis A, Corey J. Acoustic rhinometric measurements of changes in velar positioning. *Cleft Palate Craniofac J.* 1995;32(1):49-54.
- Sondhi MM, Gopinath B. Determination of vocal-tract shape from impulse response at the lips. *J Acoust Soc Am.* 1971;49(6):1867-73.
- Hilberg O, Pedersen OF. Acoustic rhinometry: recommendations for technical specifications and standard operating procedures. *Rhinol Suppl.* 2000;16:3-17.
- Bressmann T, Sell D. Plus ça change: selected papers on speech research from the 1964 issue of the *Cleft Palate Journal.* *Cleft Palate Craniofac J.* 2014;51(2):124-8.
- Warren DW, Dubois AB. A pressure-flow technique for measuring velopharyngeal orifice area during continuous speech. *Cleft palate J.* 1964;16:52-71.
- Warren DW. Aerodynamics assessment of velopharyngeal performance. In: Bzoch KR, editor. *Communicative disorders related to cleft lip and palate.* 3th ed. Austin: Little-Brown; 1989. p. 230-45.
- Zajac DJ. Speech aerodynamics of cleft palate. In: Kummer AW, editor. *Cleft palate and craniofacial anomalies: the effects on speech and resonance.* San Diego: Singular Thomson Learning; 2001. p. 377-98.
- Yamashita RP, Trindade IEK. Exames instrumentais aplicados às funções orofaciais. In: Marchesan IQ, Silva IJ, Tomé MC, editores. *Tratado das especialidades em fonoaudiologia.* São Paulo: Roca; 2014. p. 488-503.
- Roithmann R, Cole P, Chapnik J, Shpirer I, Hoffstein V, Zamel N. Acoustic rhinometry in the evaluation of nasal obstruction. *Laryngoscope.* 1995; 105(3 Pt 1):275-81.
- Gomes AOC, Sampaio-Teixeira ACM, Trindade SHK, Trindade IEK. Nasal cavity geometry of healthy adults assessed using acoustic rhinometry. *Braz J Otorhinolaryngol.* 2008;74(5):746-54.
- Warren DW. Aerodynamics assessment and procedures to determine extent of velopharyngeal inadequacy. In: Bzoch KR, editor. *Communicative disorders related to cleft lip and palate.* 4th ed. Austin: Pro-Ed; 1997. p. 411-37.
- Corey JP, Gungor A, Nelson R, Liu X, Fredberg J. Normative standards for nasal cross-sectional areas by race as measured by acoustic rhinometry. *Otolaryngol Head Neck Surg.* 1998;119(4):389-93.
- Fukushiro AP, Yamashita RP, Sampaio AC, Trindade IE. Velopharyngeal closure following pharyngeal flap surgery assessed by pressure-flow technique. In: 10th International Congress on Cleft Palate and Related Craniofacial Anomalies; 2005. Set 04-08. Durban, South Africa. Final programme & book of abstracts. p. 202-3.
- Warren DW. Compensatory speech behaviors in individuals with cleft palate: a regulation/control phenomenon? *Cleft Palate J.* 1986;23(4):251-60.
- Flores RE. A Medicina baseada em evidências e o diagnóstico laboratorial. *NewsLab.* 2005;73:92-103.
- Nohara K, Tachimura T, Wada T. Levator veli alatine muscle fatigue during phonation in speakers with cleft palate with borderline velopharyngeal incompetence. *Cleft Palate Craniofac J.* 2006;43(1):103-7.
- Kummer AW. Cleft palate and craniofacial anomalies: the effects on speech and resonance. San Diego: Singular; 2001. 481 p.
- Vidotti BA, Trindade IEK. Os efeitos da expansão rápida da maxila sobre a permeabilidade nasal avaliados por rinomanometria e rinometria acústica. *Rev Dent Press Ortodon Ortop Facial.* 2008;13(6):59-65.