

# Velar activity in individuals with velopharyngeal insufficiency assessed by acoustic rhinometry

Inge Elly Kiemle TRINDADE<sup>1</sup>, Bruna Mara Adorno Marmontel ARAÚJO<sup>2</sup>, Ana Claudia Martins Sampaio TEIXEIRA<sup>2</sup>, Andressa Sharllene Carneiro da SILVA<sup>2</sup>, Ivy Kiemle TRINDADE-SUEDAM<sup>1</sup>

1- Department of Biological Sciences, Bauru School of Dentistry, University of São Paulo; Laboratory of Physiology, Hospital for Rehabilitation of Craniofacial Anomalies, University of São Paulo, Bauru, SP, Brazil.

2- Laboratory of Physiology, Hospital for Rehabilitation of Craniofacial Anomalies, University of São Paulo, Bauru, SP, Brazil.

**Corresponding address:** Inge Elly Kiemle Trindade - Laboratório de Fisiologia, Hospital de Reabilitação de Anomalias Craniofaciais Universidade de São Paulo - Rua Silvio Marchione 3-20 - 17.012-900 - Bauru-SP - Brasil - Fax: 55(14)3224-1590 - Phone: 55(14)3235-8137 - e-mail: ingetrin@usp.br

**Submitted:** December 16, 2013 - **Modification:** February 19, 2014 - **Accepted:** February 20, 2014

## ABSTRACT

Acoustic rhinometry is routinely used for the evaluation of nasal patency. Objective: To investigate whether the technique is able to identify the impairment of velopharyngeal (VP) activity in individuals with clinical diagnosis of velopharyngeal insufficiency (VPI). Methods: Twenty subjects with repaired cleft palate and inadequate velopharyngeal function (IVF) and 18 non-cleft controls with adequate velopharyngeal function (AVF), adults, of both genders, were evaluated. Area-distance curves were obtained during VP rest and speech activity, using an Eccovision Acoustic Rhinometry system. Volume was determined by integrating the area under the curve at the segment corresponding to the nasopharynx. VP activity ( $\Delta V$ ) was estimated by the absolute and relative differences between nasopharyngeal volume at rest ( $V_r$ ) and during an unreleased /k/ production ( $V_k$ ). The efficiency of the technique to discriminate IVF and AVF was assessed by a ROC curve. Results: Mean  $V_k$  and  $V_r$  values ( $\pm$ SD) obtained were:  $23.2 \pm 3.6 \text{ cm}^3$  and  $15.9 \pm 3.8 \text{ cm}^3$  (AVF group), and  $22.7 \pm 7.9 \text{ cm}^3$  and  $20.7 \pm 7.4 \text{ cm}^3$  (IVF group), corresponding to a mean  $\Delta V$  decay of  $7.3 \text{ cm}^3$  (31%) for the AVF group and a significantly smaller  $\Delta V$  decay of  $2.0 \text{ cm}^3$  (9%) for the IVF group ( $p < 0.05$ ). Seventy percent of the IVF individuals showed a  $\Delta V$  suggesting impaired VP function (below the cutoff score of  $3.0 \text{ cm}^3$  which maximized both sensitivity and specificity of the test), confirming clinical diagnosis. Conclusion: Acoustic rhinometry was able to identify, with a good discriminatory power, the impairment of VP activity which characterizes VPI.

**Keywords:** Acoustic rhinometry. Velopharyngeal insufficiency. Nasopharynx.

## INTRODUCTION

Acoustic rhinometry (AR) is widely recognized as a technique for the evaluation of nasal cavity geometry by acoustic reflection<sup>4,8,17</sup>. It allows the measurement of sectional areas and volumes of consecutive nasal segments, including the nasopharynx, leading Dalston<sup>5</sup> (1992) to suggest the use of the technique to monitor changes in velopharyngeal (VP) activity during "silent" speech. Seaver, et al.<sup>14</sup> (1995) were the first to demonstrate the decrease in nasopharyngeal volume caused by velar elevation above the palatal plane, by comparing rhinometric findings with videofluoroscopic images of the nasopharyngeal region during speech in

two normal non-cleft volunteers. Kunkel, et al.<sup>10</sup> (1998) added experimental evidences to these preliminary observations. Also in volunteers, the authors observed excellent correlation between the decrease in nasopharyngeal volume caused by insufflation of a cuff at the nasopharynx, measured by AR, and the volume of water used to insufflate the cuff. The authors also examined individuals with cleft palate. By comparing nasopharyngeal volumes at rest and during a speech activity they observed that maximum VP mobility was significantly lower in the cleft group than in a control non-cleft group<sup>10,11</sup>.

Considering that acoustic rhinometry is a simple, objective and non-invasive method, and considering the importance to validate the

technique for the clinical practice, this study was designed to determine whether clinical diagnosis of velopharyngeal insufficiency (VPI) is associated with no significant changes in nasopharyngeal volume due to velar and/or pharyngeal walls movement as assessed by acoustic rhinometry. With this purpose, VP activity of individuals with repaired cleft palate and clinical diagnosis of inadequate velopharyngeal function (IVF) was compared to that of individuals without cleft palate and adequate velopharyngeal function (AVF). A secondary objective was to analyze the sensitivity and specificity of the method.

## MATERIAL AND METHODS

The study was reviewed and approved by the Institutional Review Board under protocol number 248/2007. Examinations were performed after signature of the informed consent form.

Twenty adults with nonsyndromic repaired cleft palate±lip, without pharyngeal flaps (13 females, aged 17 to 35 years), were analyzed. Only individuals diagnosed as having IVF were included in the study. For control purposes, 18 volunteers without cleft lip or palate (12 females, aged 20 to 35 years), diagnosed as having AVF were evaluated. Diagnosis of IVF and AVF was first done perceptually by two speech pathologists with experience in cleft speech, after consensus. IVF diagnosis was further confirmed by routine nasopharyngoscopy performed in all subjects of the cleft group for secondary surgery planning. Individuals with physical/mental inability for accomplishing exams, residual palatal fistulas or nasal obstruction at the moment of examination were excluded from the study.

Perceptual speech assessment was performed during spontaneous conversation and standardized sentences and words in Brazilian Portuguese, in order to identify hypernasality, nasal air emission and compensatory articulations. VP

function was classified according to a 6-point scale. Hypernasality and nasal air emissions were scored as 1=absent, 2=mild, 3=mild to moderate, 4=moderate, 5=moderate to severe, and 6= severe, and compensatory articulations were scored as 1=absent and 2=present. Scores equal to or higher than 2 were considered clinically significant for hypernasality and higher than 3 for nasal air emission. Depending on the combination of scores observed for hypernasality, nasal emission and compensatory articulation, VP function was then scored on a 3-point scale, as 1=adequate, 2=borderline and 3=inadequate (Figure 1). Only individuals with inadequate function were included in the study.

Rhinometric evaluation was performed using an Eccovision Acoustic Rhinometer (HOOD Laboratories, Pembroke, MA, USA). The system is composed of a tube (24 cm long) with a sound source (loudspeaker) at the distal end and a microphone at the proximal end. During examination, the tube tip, protected by a silicon piece (nosepiece), is positioned against one of the nostrils. The sound wave generated by the loudspeaker travels along the tube, passes the microphone without sensitizing it, and enters the nasal cavity. Changes in the cross-sectional areas, i.e. constrictions along the cavity, cause the sound wave to reflect back into the tube. The reflected sounds are sensed by the microphone and then amplified and digitized. A microcomputer with specific software is used for data analysis. Ten pulses are generated at approximately every 0.5 second.

Nasal cross-sectional areas from the nostril to the nasopharynx are calculated by the software based on the reflected sound intensity. Distances of the segments in relation to the nostrils are calculated based on the wave speed and time of arrival. Data are converted into an area-distance function and represented on the computer screen as a graph, the rhinogram, in which the area (in cm<sup>2</sup>) is

Hypernasality*	Speech characteristics		
	Nasal air emission*	Compensatory articulations#	Velopharyngeal function
1	1	1	1=adequate
1	2	1	1=adequate
1	3	1 – 2	2=borderline
2	1 – 3	1 – 2	2=borderline
3	1 – 3	1 – 2	2=borderline
2	4 – 6	1 – 2	3=inadequate
3	4 – 6	1 – 2	3=inadequate
4 – 6	2 – 6	1 – 2	3=inadequate

\*1=absent, 2=mild, 3=mild to moderate, 4=moderate, 5=moderate to severe, 6=severe

# 1=absent, 2=present

**Figure 1-** Criteria used to classify velopharyngeal function on speech perceptual assessment

presented in a semi-logarithmic scale on the y axis and the distance (in cm) is presented on the x axis (Figure 2A). Volumes are calculated by integrating the area under the curve (Figures 2B and 2C). The software calculates the mean sectional areas and volumes of the ten repetitions.

Measurements were performed during VP rest (soft palate and pharyngeal walls relaxed) and during maximum VP activity (soft palate and/or pharyngeal walls in movement). With the rhinometer tube positioned and after some rest breathing cycles, the patient was asked first to voluntarily interrupt breathing at end-expiration (rest condition) and then the data acquisition was done. Assessments were performed in each nasal side. The side with the highest mean cross-sectional area of the nasal valve (second dip of the rhinogram) was selected for analysis and further assessment<sup>7,17</sup>. Thereafter, the patient was asked to produce the word /'kaza/. Measurements were done while the subject sustained intraoral pressure of the voiceless velar stop /k/, and thus palatal muscle tension, for nearly 5 seconds, until completion of data acquisition. Considering that the stop production has three phases, i.e. closure, release and affrication, measurements were done during an unreleased /k/. Because of that, seven speakers out of the twenty with compensatory articulation related to the cleft and velar place of production preserved were included in the study.

Assessments during rest and activity were repeated until three technically acceptable rhinograms were obtained. A good consistency over time was observed so that usually the first three rhinograms were considered for analysis. Two different rhinograms were analyzed, i.e., the rhinogram with the highest nasopharyngeal volume at rest and the rhinogram with the highest nasopharyngeal volume during speech activity. This criteria was adopted to ensure that the palate was as relaxed as possible during rest position. Tongue movement was a non-controlled variable.

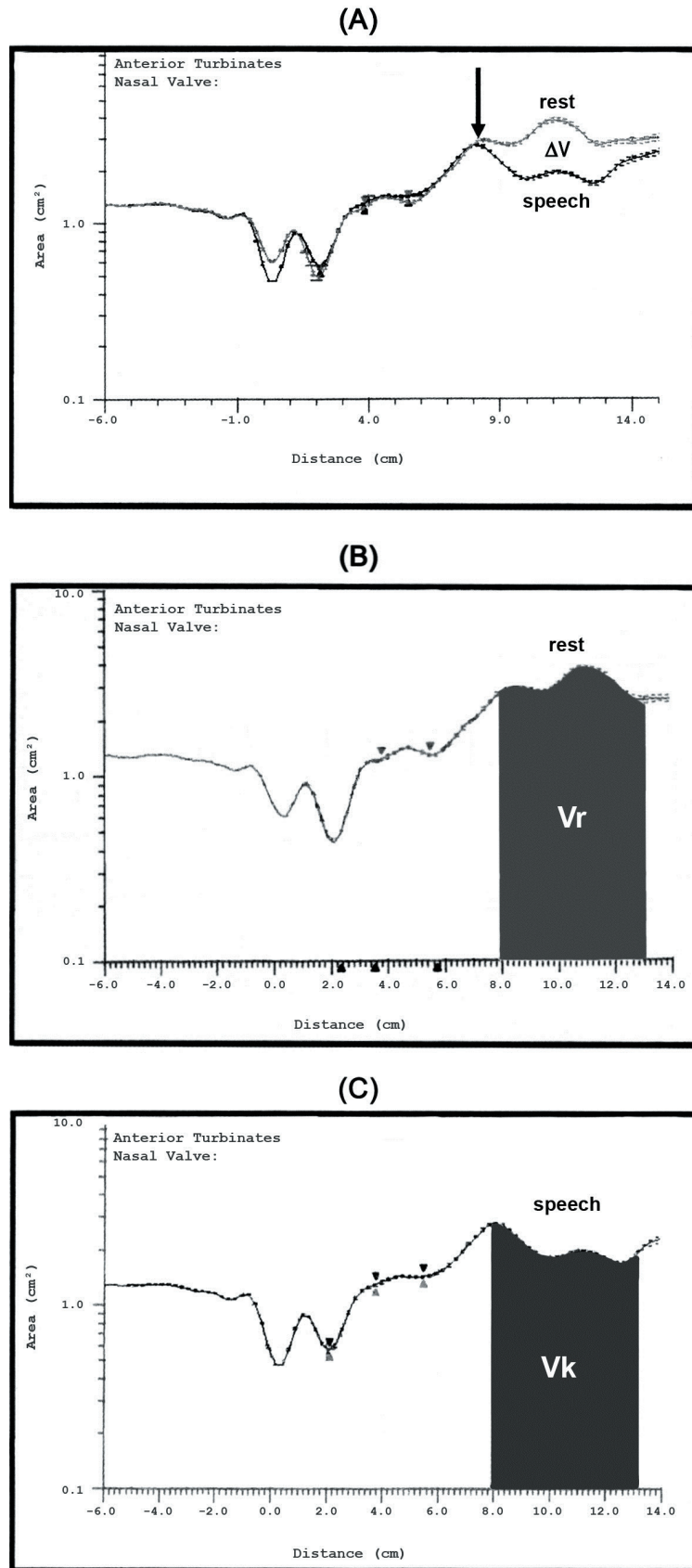
Rhinograms obtained at rest and in activity were superimposed as shown in Figure 2. Nasopharyngeal volume was determined by integrating the area under the curves, from the divergence point between the rest and activity curves, which corresponds to the posterior edge of the hard palate (or choanal region), up to 5 cm from this point. By doing so, divergence between curves indicate velar and/or pharyngeal movement. In eight cases in the IVF group, the curves did not depart from each other, that is, the point of divergence between the curves was not clearly observed, because of the lack of VP activity. In these cases, the initial point of measurement was taken as the mean distance observed in the control group, which corresponded to 7.7 cm from the nostrils, and nasopharyngeal volume was calculated for the

interval between 7.7 up to 12.7 cm in relation to the nostrils. Thus, in both situations, a segment of 5 cm was analyzed from the choana, corresponding to the nasopharynx.

VP activity was determined by calculating the difference between the nasopharyngeal volumes at rest ( $V_r$ ) and during /k/ production ( $V_k$ )<sup>10,11</sup> and results were expressed as absolute ( $\Delta VA = V_k - V_r$ ) and relative ( $\Delta VR = V_k - V_r / V_r$ ) differences<sup>11</sup>, in order to eliminate interferences caused by acoustic reflection to the contralateral nasal cavity or paranasal sinuses, which might overestimate the measurements; presence of significant obstructions anteriorly to the nasopharynx, which might underestimate the measurements; voluntary or involuntary palatal movements and respiratory effort<sup>2,3,6,9</sup>.

The equipment was calibrated before each session of assessments. The examinations were always performed in the same room, at a relatively stable temperature and with noise level below 60 db, after a period of 30 minutes for patient's adaptation to the environmental conditions. The rhinometer tube was always positioned parallel to the nose dorsum and the sealing between the nosepiece and the nasal cavity was assured by using a neutral electrocardiogram gel to avoid sound loss. Also, the subject underwent the examination in seated position, with the mentum and forehead supported on a stand especially designed for that purpose, mounted in a rod fixated to the chair. When the examinations were performed at rest, the subjects were asked to maintain the mouth closed, without swallowing or moving the tongue during data acquisition, to avoid interference from breathing and swallowing on the quality of rhinograms. Care was also taken to avoid deformation to the nostril and thus to the nasal valve during the procedure<sup>7,16,18</sup>.

Considering that the variable "volume" had normal distribution, the results are expressed as mean  $\pm$  standard deviation. The significance of differences between conditions (VP rest and activity), and groups (AVF and IVF), was evaluated by two-way mixed analysis of variance. The *post hoc* comparisons were performed by the Tukey test. All tests were applied at a significance level of 5%. The sensitivity and specificity of the technique as diagnostic test was analyzed by using the Receiver Operating Characteristic (ROC) curve, for different absolute  $\Delta V$  values. The one which simultaneously maximized sensitivity and specificity was considered a cutoff score for discriminating individuals with adequacy from those with impairment of VP activity<sup>13,19</sup>.



**Figure 2-** Tracing A shows two superimposed rhinograms obtained during VP rest and activity. Divergence between curves indicates velar and/or pharyngeal movement. Tracings (B) and (C) show the segments used to determine the nasopharyngeal volume ( $V_k$  and  $V_r$ ) by integration of the area under the curve

## RESULTS

### Mean nasopharyngeal volumes at VP rest and activity

Results obtained at rest and in activity in 18 individuals with AVF and 20 individuals with IVF are shown in Table 1. At rest, mean nasopharyngeal volumes did not differ between groups, indicating equivalent nasopharyngeal dimensions. Differences between rest and speech activity volumes were significant for both groups, however, the volume decay ( $\Delta VA$ ) was significantly lower in the IVF group (7.3 vs. 2.0  $\text{cm}^3$ ), corresponding to a relative difference ( $\Delta VR$ ) of 31% and 9%, respectively, values that also differed significantly from each other.

### Sensitivity and specificity of acoustic rhinometry

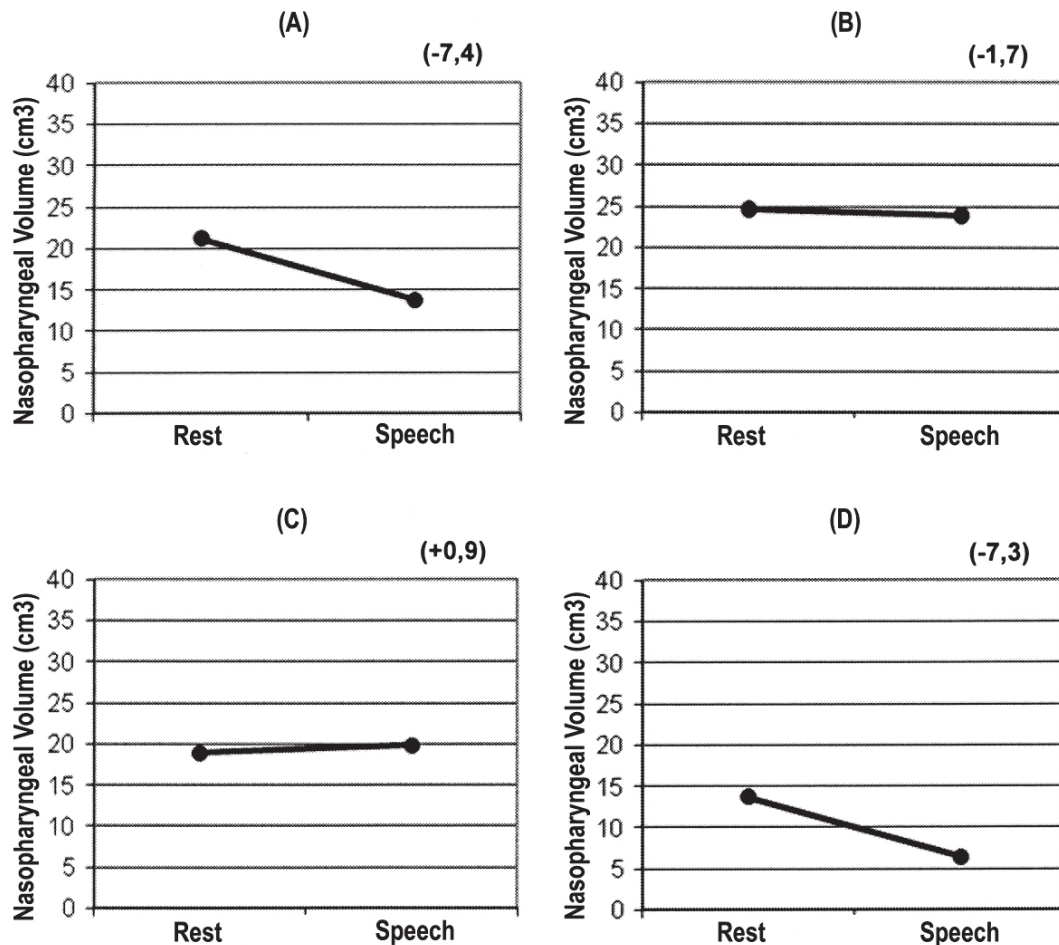
The  $\Delta VA$  value which simultaneously maximized the sensitivity and specificity of the test corresponded to 2.965, as determined by the ROC curve. Therefore, volumetric decays smaller than 3.0 were

interpreted as IVF. When using that cutoff score, the sensitivity and specificity corresponded to 0.70 and 1.00, respectively. A sensitivity of 0.70 means that the test has correctly recognized 70% of the individuals with IVF. A specificity of 1.00 means that the test has correctly identified all individuals (100%) with AVF.

### Individual nasopharyngeal volumes at VP rest and activity

All subjects in the AVF group had a  $\Delta VA$  above the cutoff score ( $>3 \text{ cm}^3$ ), suggesting adequate VP function. The minimum and maximum values observed corresponded to 3.1 and 18.6  $\text{cm}^3$ , respectively. Figure 3A shows an illustrative case of the AVF group.

In the IVF group, 9 out of the 20 individuals had decreases in nasopharyngeal volume smaller than the cutoff score ( $\Delta VA < 3 \text{ cm}^3$ ), confirming lower nasopharyngeal volume changes being associated with a clinical diagnosis of VPI, as the example shown in Figure 3B. Other 5 individuals exhibited small increases ( $<3 \text{ cm}^3$ ), which were not observed



**Figure 3-** Absolute nasopharyngeal volumes at VP rest and activity. (A) suggests good velopharyngeal structures movement in an individual judged to have adequate velopharyngeal function. (B) and (C) poor movement in individuals judged to have inadequate velopharyngeal function. (D) good movement in an individual judged to have inadequate velopharyngeal function



**Table 1-** Nasopharyngeal volumes: mean values±standard deviation, minimum and maximum values, absolute difference ( $\Delta VA$ ) and relative difference ( $\Delta VR$ ), observed at velar rest and speech, in individuals with adequate (AVF) and inadequate (IVF) velopharyngeal function

	Volumes (cm <sup>3</sup> )			
	Velar Rest (Vr)	Speech (Vk)	$\Delta VA$ (Vk-Vr)	$\Delta VR\%$ (Vk-Vr/Vr)
AVF (n=18)	23.2±6.4 (14.6-35.1)	15.9±3.8* (9.4-21.7)	-7.3	-31%
IVF (n=20)	22.7±7.9 (10.5-37.1)	20.7±7.4*# (6.5-34.2)	-2.0#	-9%#

\*  $p < 0.05$  statistically significant difference (velar rest vs. speech)

#  $p < 0.05$  statistically significant difference (AVF vs. IVF)

in any individual in the control group (Figure 3C), also suggesting inadequate VP activity. Thus, low volumetric changes were observed in a total of 14 (70%) patients. Conversely, 6 individuals had a significant decrease of nasopharyngeal volume (above the cutoff score), comparable to the control group, suggesting good VP activity despite VPI symptoms (Figure 3D).

## DISCUSSION

Based on the rationale that velar elevation and possibly pharyngeal walls movement change nasopharyngeal dimensions, the present study reinforces Dalston's<sup>5</sup> (1992) assumption that acoustic rhinometry is a helpful tool for assessing VP activity in individuals with VPI. This is the first report of a series of ongoing studies at our laboratory to validate the technique as a method for evaluating the movement of VP structures in speech.

As a first approach, the volumetric change of the nasopharynx produced by speech activity that requires maximum velar elevation (unreleased /k/) was determined in normal individuals, followed by the analysis of the impact of VPI. The results demonstrated that acoustic rhinometry was able to discriminate a significant percentage of individuals with IVF from those with AVF. However, a subgroup of individuals with good VP movement, despite VPI symptoms, was also identified.

The current findings are in accordance with Seaver, et al.<sup>14</sup> (1995) which validated rhinometric outcomes against anatomic data. In a pilot study, the authors analyzed VP activity of two normal speakers on simultaneous videofluoroscopy and rhinometry recordings. Measurements were obtained during velar rest (open VP orifice), and during production of a "silent" /f/ (closed VP orifice), assuming that the differences would be caused by VP activity. The change in velar positioning was monitored by comparing aligned videofluoroscopic

frames and superimposed rhinograms, obtained at rest and in activity, as in the present study. Inspection of the rhinograms showed that they started to depart from each other at a distance of 7 to 8 cm from the nosepiece (nostrils) in both adults analyzed, confirming data obtained in the control group of the current study, in which the divergence point was located at 7.7 cm from the nostrils, on average. Seaver, et al.<sup>14</sup> (1995) also observed excellent agreement between the results of both techniques. Videofluoroscopy showed that the soft palate elevated above the palatal plane at 7.4 cm from the nostrils, in both cases, a value very close to those obtained with acoustic rhinometry (7.6 and 7.3 cm, respectively).

In the current investigation, the plosive /k/ was used instead of the fricative /f/, as done by Kunkel, et al.<sup>10,11</sup> (1998), who did not explain the rationale for using another stimulus. The /k/ production was chosen based on a pilot study which showed that individuals with VPI may present unstable curves during the "silent" production of /f/, probably due to sound contamination by an unavoidable air friction in nasal and oral passages. Because of that, the plosive /k/ was assessed, which was proven to be less prone to the instabilities observed for the fricative sound. The stimuli was produced in the word /'kaza/, in an attempt to standardize the respiratory effort as much as possible.

As to the results observed in the AVF group, the analysis of  $\Delta V$  mean values showed a significant reduction of the nasopharyngeal volume of 7.3 cm<sup>3</sup> (31%), close to the 8.0 cm<sup>3</sup> reported by Kunkel, et al.<sup>10,11</sup> (1998). Conversely, the group with IVF presented a non-significant volumetric reduction of only 2.0 cm<sup>3</sup> (9%), suggesting poor VP activity, and thus confirming the clinical diagnosis. Kunkel, et al.<sup>10,11</sup> (1998) observed greater variation in individuals with cleft (6.5 cm<sup>3</sup>). The difference is probably related to the sample characteristics. In the current study, all IVF individuals had non-

syndromic repaired cleft palate, VPI and no flaps. Individuals with marginal VP closure were not included, which may at least partly explain the lower value observed. Preliminary results of an ongoing study at our laboratory have shown that marginal closures yield intermediate decays in nasopharyngeal dimensions.

Thus, analysis of mean volumes led us to conclude that acoustic rhinometry is capable of discriminating individuals with and without impairment of VP function. Individual analysis of data allowed further inferences. Two types of response were observed during speech activity: in most individuals (70% of the IVF cases analyzed), a poor VP activity was indeed observed (small volumetric changes, with increases or decreases smaller than the cutoff value of 3.0 cm<sup>3</sup>). However, differently than expected, 30% of cases presented volumetric changes comparable to the control group (greater than the cutoff value), even though they had been clinically diagnosed as presenting VPI. The overlapping of cases and controls was also observed by Kunkel, et al.<sup>10,11</sup> (1998), what led these authors to disregard the use of a threshold value to discriminate normal and pathological VP function. Our results do not support this assumption. Analysis of the sensitivity and specificity of the technique, though somewhat limited by the sample size, was high for the cutoff value of 3.0 cm<sup>3</sup> (0.70 and 1.00, respectively). To obtain "false negatives" is not a desirable finding in any clinical test. However, a 70% of agreement with a standard test is not a negligible outcome in terms of instrumental analysis.

On the other hand, anatomical and physiological evidences may explain the occurrence of those "false negatives" (clinical diagnosis of VPI and good VP movement under acoustic rhinometry). A good movement outcome in the rhinometric assessment is mainly attributable to velar elevation. However, it is well known that the VP mechanism involves not only the posterior and superior movement of the soft palate, but also the mesial movement of lateral pharyngeal walls, and to a lesser extent the anterior movement of the posterior pharyngeal wall. Since the relative participation of these components varies among individuals<sup>15</sup>, VPI symptoms like hypernasality, in the presence of good velar movement, might be assigned to the absence of lateral pharyngeal walls movement, as may have been the case for some of the subjects presently analyzed. Preliminary findings of an ongoing study in our laboratory show that there is a relationship between the degree of VP activity assessed by acoustic rhinometry and the type and degree of closure observed on the nasopharyngoscopic examination. Tongue participation in velar elevation cannot be ruled out as well. Studies combining acoustic rhinometry and ultrasound data of tongue

motion would be helpful to answer this question<sup>1</sup>.

Another possibility should explain the occurrence of "false negatives". In individuals with clefts, surgical reconstruction of the soft palate may provide the anatomical conditions for VP closure, but may not provide adequate functional conditions for sustaining velar elevation due to muscle contact force deficiency or muscle fatigue<sup>12</sup>, or even because of timing problems<sup>20</sup>, explaining why subjects had hypernasality in the presence of good velar movement.

## CONCLUSION

Acoustic rhinometry is not supposed to replace the gold standard techniques used for diagnosing VPI, i.e., nasoendoscopy or videofluoroscopy. Instead, current data ultimately demonstrate that the technique, like nasometry and flow-pressure studies, should be used as a complementary method of VP function assessment. Differently from the formers, acoustic rhinometry is appropriate for studying changes in VP mobility induced by behavioral or physical procedures. This is enhanced because the technique is easy and quick to perform, and is well tolerated by the patients. As anticipated by earlier studies, it may be a useful tool for the evaluation of the outcomes of therapeutic interventions, such as the use of palatal prostheses for encouraging pharyngeal walls movement, and for assessing the outcomes of surgical procedures aiming to improve velar movement, such as intravelar veloplasty. A study from our laboratory is currently investigating this latter issue.

## ACKNOWLEDGEMENTS

The authors would like to thank FAPESP - São Paulo Research Foundation (process number 2000/04354-1), CNPq - National Council for Scientific and Technological Development, and CAPES - Coordination of Higher Education and Graduate Training for the financial support.

## REFERENCES

- 1- Bressmann T, Radovanovic B, Kulkarni GV, Klaiman P, Fisher D. An ultrasonographic investigation of cleft-type compensatory articulations of voiceless velar stops. *Clin Linguist Phon.* 2011;25(11-12):1028-33.
- 2- Cakmak O, Tarhan E, Coskun M, Cankurtaran M, Celik H. Acoustic rhinometry: accuracy and ability to detect changes in passage area at different location in the nasal cavity. *Ann Otol Rhinol Laryngol.* 2005;114(12):949-57.
- 3- 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):169-79.
- 4- Corey JP. Acoustic rhinometry: should we be using it? *Curr Opin Otolaryngol Head Neck Surg.* 2006;14(1):29-34.

- 5- Dalston RM. Acoustic assessment of the nasal airway. *Cleft Palate Craniofac J.* 1992;29(6):520-6.
- 6- Fisher EW, Morris DP, Biemans JM, Palmer CR, Lund VJ. Practical aspects of acoustic rhinometry: problems and solutions. *Rhinology.* 1995;33(4):219-23.
- 7- Gomes AO, Sampaio-Teixeira AC, Trindade SH, Trindade IE. Nasal cavity geometry of healthy adults assessed using acoustic rhinometry. *Braz J Otorhinolaryngol.* 2008;74:746-59.
- 8- Hilberg O, Jackson AC, Swift DL, Pedersen OF. Acoustic rhinometry: evaluation of nasal cavity geometry by acoustic reflection. *J Appl Physiol.* 1989;66(1):295-303.
- 9- Hilberg O, Jensen FT, Pedersen OF. Nasal airway geometry: comparison between acoustic reflections and magnetic resonance scanning. *J Appl Physiol (1985).* 1993;75(6):2811-9.
- 10- Kunkel M, Wahlmann U, Wagner W. Objective evaluation of velopharyngeal function by acoustic reflection measurements. *Mund Kiefer Gesichtschir.* 1998;2(Sp. Issue):S158-62.
- 11- Kunkel M, Wahlmann U, Wagner W. Objective, noninvasive evaluation of velopharyngeal function in cleft and noncleft patients. *Cleft Palate Craniofac J.* 1998;35(1):35-9.
- 12- Moon JB, Kuehn DP. Anatomy and physiology of normal and disordered velopharyngeal function for speech. In: Bzoch KR, editors. *Communicative disorders related to cleft lip and palate.* Austin: Pro-Ed; 2004. p. 67-98.
- 13- Park SH, Goo JM, Jo CH. Receiver operating characteristic (ROC) curve: practical review for radiologists. *Korean J Radiol.* 2004;5(1):11-8.
- 14- 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.
- 15- Skolnick ML, McCall GN, Barnes M. The sphincteric mechanism of velopharyngeal closure. *Cleft Palate J.* 1973;10:286-305.
- 16- Trindade IE, Castilho RL, Sampaio-Teixeira AC, Trindade-Suedam IK, Silva-Filho OG. Effects of orthopedic rapid maxillary expansion on internal nasal dimensions in children with cleft lip and palate assessed by acoustic rhinometry. *J Craniofac Surg.* 2010;21(2):306-11.
- 17- Trindade IE, Conegliam PC, Trindade SH, Dias NH, Sampaio-Teixeira AC. Internal nasal dimensions of adults with nasal obstruction. *Braz J Otorhinolaryngol.* 2013;79(5):575-81.
- 18- Trindade IE, Gomes AO, Sampaio-Teixeira AC, Trindade SH. Adult nasal volumes assessed by acoustic rhinometry. *Braz J Otorhinolaryngol.* 2007;73:32-9.
- 19- Vig OS, Spalding PM, Lints RR. Sensitivity and specificity of diagnostic tests for impaired nasal respiration. *Am J Orthod Dentofacial Orthop.* 1991;99(4):354-60.
- 20- Warren DW, Dalston RM, Mayo R. Hyponasality in the presence of "adequate" velopharyngeal closure. *Cleft Palate Craniofac J.* 1993;30(2):150-4.