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Original articles

Anatomical and functional characterization of the hypodynamic velopharynx in individuals with cleft palate

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ABSTRACT

Purpose: to characterize the velopharyngeal function of individuals presented with velopharyngeal dysfunction, suggestive of a hypodynamic velopharynx.

Methods: the sample comprised nasoendoscopy examinations from adult subjects with repaired cleft palate, no fistula, velopharyngeal dysfunction, and a probable diagnosis of hypodynamic velopharynx. All participants used a pharyngeal bulb prosthesis and had never undergone speech therapy for velopharyngeal dysfunction. Three speech-language pathologists assessed the movement of velopharyngeal structures. The results were analyzed using descriptive statistics, the Kappa being employed to measure intra-rater agreement.

Results: out of the 28 recordings, 23 (82%) exhibited minimal mobility of the soft palate and lateral pharyngeal walls, with a large residual velopharyngeal gap. Additionally, 23 (82%) showed no antagonistic movement, and the Passavant's ridge was present in 7 (25%). Regarding the type, 16 (57%) had a circular gap, 8 (28%) had a circular gap with a Passavant´s ridge, 3 (10%) had a coronal gap, and 1 (5%) had a sagittal one. There was no movement of the posterior pharyngeal wall in 14 (50%) recordings. Agreement was considered almost perfect for all aspects analyzed (Kappa = 1.00).

Conclusion: subjects presented with velopharyngeal dysfunction, indicative of a hypodynamic velopharynx, exhibited a velopharyngeal gap equal to or greater than 50% of the resting size of the velopharyngeal space, with minimal movement of the soft palate and pharyngeal walls.

Keywords: Cleft Palate; Velopharyngeal Insufficiency; Palatal Obturators; Speech

A study conducted at the University of São Paulo, Hospital for Rehabilitation of Craniofacial Anomalies, Bauru, SP, Brazil.

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INTRODUCTION

The accurate production of speech relies on the proper functioning of the velopharyngeal mechanism (VPM). This mechanism separates the oral and nasal cavities and manages the air pressures required for speech production. Normally, the VPM should close during the production of oral phonemes and open during the emission of nasal phonemes. This dynamics is regulated by the nasality feature of the phoneme being produced. The closure of the VPM involves the elevation and retraction of the soft palate, the movement of the posterior pharyngeal wall, and the medialization of the lateral pharyngeal walls[1].

Velopharyngeal dysfunction (VPD) describes the misalignment in the movement required to open and/or close the velopharyngeal gap, which affects speech and swallowing functions[2]. The most characteristic clinical sign of VPD is hypernasality, which may be accompanied by nasal air emission. These alterations, whether occurring in isolation or combination, can impair speech intelligibility and impact social interactions[3-6]. In individuals with repaired cleft palate, the most common causes of VPD are velopharyngeal insufficiency (a deficiency of tissue in the soft palate) and/or errors in learning the movement of the pharyngeal walls[1,2,7].

Hypodynamic velopharynx is regarded as learning error that may or may not be associated with velopharyngeal insufficiency (VPI). It involves the formation of a velopharyngeal gap (an opening at the point of maximum contraction of the velopharyngeal structures greater than 50% of the velopharyngeal space at rest, with minimal or no movement of the pharyngeal walls during speech[8]. Additionally, this condition may also include "antagonistic movement" of the lateral walls during the production of oral phonemes[9].

Since treatment for different causes of VPD varies, a differential diagnosis is cruciall[8-10]. Typically, secondary surgery (such as repalatoplasty or pharyngoplasty) is preferred for individuals with VPI, while speech therapy is recommended for those with VPD resulting from learning errors[9,11,12]. However, as the choice of surgical technique takes into account the presence of velopharyngeal movement, individuals with a hypodynamic velopharynx often have poor surgical prognosis due to limited movement. In these cases, a pharyngeal bulb prosthesis is recommended, usually combined with a speech therapy program, to optimize velopharyngeal conditions and improve surgical outcomes[9,12-14].

As the literature on hypodynamic velopharynx is still quite limited, this study addresses the need to document and publish knowledge about the identification of this condition, which could contribute to the differential diagnosis of the causes of VPD and its treatment, thereby providing greater effectiveness in the rehabilitation process. Thus, the present study aimed at characterizing the velopharyngeal function of individuals with VPD, suggestive of a hypodynamic velopharynx.

METHODS

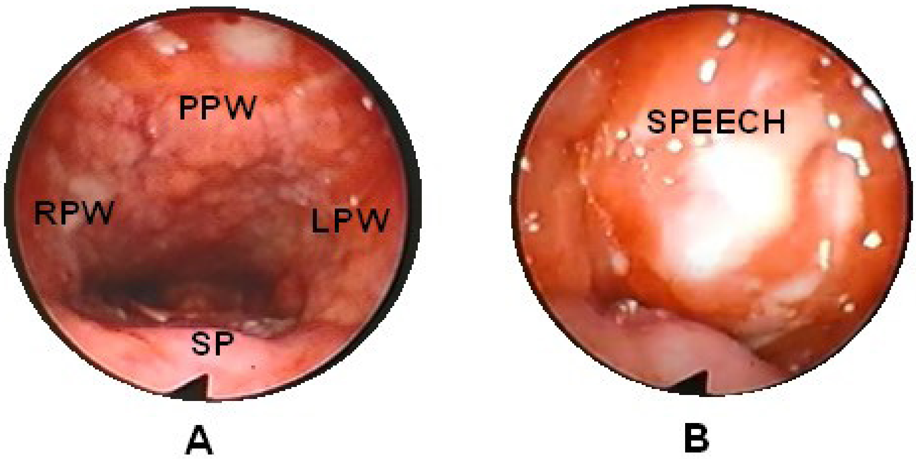
This study was approved by the Research Ethics Committee of the Hospital for Rehabilitation of Craniofacial Anomalies at the University of São Paulo (HRAC/USP), Bauru, SP, Brazil, under the approval number (No. 5.217.676 - SVAPEPE – CEP2021 – CAEE 54028521.8.0000.5441). As this study involves secondary data (recordings of nasoendoscopy exams) that were pre-existing in the originating institution, authorization was requested from the subjects to analyze their nasoendoscopy exams archived at the institution. After an initial contact by phone, a link to the Informed Consent Form (ICF) was sent by email to all subjects who agreed to participate in the study. The ICF was completed in a virtual format using the Google Forms tool.

Selection of nasoendoscopy recordings

The sample for this study consisted of a convenience sample of video recordings from nasoendoscopy exams of male and female subjects who exhibited VPD following primary palatal surgery. Video-recordings from subjects treated at the Palatal Prosthesis Service of HRAC-USP were selected, based on the following inclusion criteria: a) a prior diagnosis of hypodynamic velopharynx (characterized by a large velopharyngeal gap and minimal or no movement of the pharyngeal walls) by the interdisciplinary team (as documented in the medical records); b) recommendation for a pharyngeal bulb prosthesis to address hypodynamic velopharynx (either temporary or permanent), reflecting the institution's practice of preferring a pharyngeal bulb prosthesis over surgery for such cases; c) absence of palatal fistula; d) minimum age of 18 years; and e) recordings with good technical quality, including both image and sound.

Edition of videonasoendoscopy samples

The image of the velopharynx at rest, followed by the counting from 1 to 10 in each recording, was cropped and edited using Capcut video editing software, version 1.3.2 (Figure 1). After editing, the samples were stored on Google Drive and made available to the evaluators.



Captions: SP = soft palate, LPW = left pharyngeal wall, RPW = right pharyngeal wall, PPW = posterior pharyngeal wall. B) Three-dimensional view of the velopharyngeal mechanism during speech.

Figure 1. A) Three-dimensional view of the velopharyngeal mechanism at rest.

Evaluation of nasoendoscopy recordings

The recorded samples from the exams were evaluated through consensus among three speech-language pathologists (SLPs) with expertise in diagnosing VPD through nasoendoscopy. Prior to the evaluations, the SLPs received detailed instructions from the researcher regarding the procedures to be followed, specifically related to the movement of the velopharyngeal structures. An adapted protocol was used for this purpose[15,16]. This protocol is a semi-quantitative measurement model designed to standardize the assessment of velopharyngeal function through nasoendoscopy. It relies on relative measures, focusing on evaluating the contrast between the resting position and the extent of movement of the pharyngeal walls. The following is a description of each aspect evaluated.

a) Movement of the soft palate: The maximum displacement was estimated with the soft palate at rest fixed at a value of 0, the posterior pharyngeal wall at rest fixed at a value of 1, and the center of the velopharyngeal space at rest fixed at a value of 0.5. According to the protocol, the maximum displacement of the soft palate could fall into one of four categories: 0-25%, 26-50%, 51-75%, or 76-100% (Figure 2).

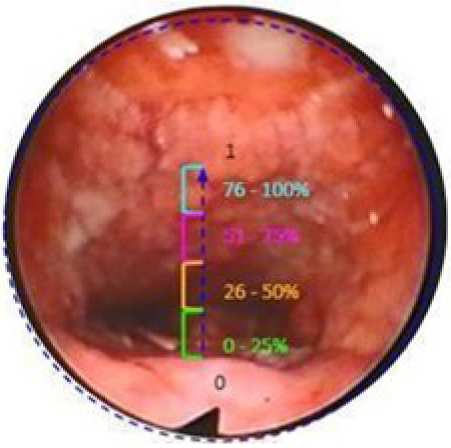


Figure 2. View of the velopharynx at rest. #1 indicates the posterior pharyngeal wall in its resting position, while #0 denotes the resting position of the velum. The green line represents the maximum displacement of the velum within 0-25% of the total space, the yellow line within the 26-50%, the pink line within 51-75%, and the turquoise line within 76-100%.

b) Movement of the right and left lateral pharyngeal walls: The maximum displacement of each wall, expressed as a percentage relative to the opposite wall, was estimated. The right wall at rest was assigned a reference value of 0, while the left wall was assigned a reference value of 1. According to the protocol, the maximum displacement of the right wall could fall into one of four categories: 0-25%, 26-50%, 51-75%, or 76-100%. The same procedure was applied to assess the displacement of the left wall (Figure 3).

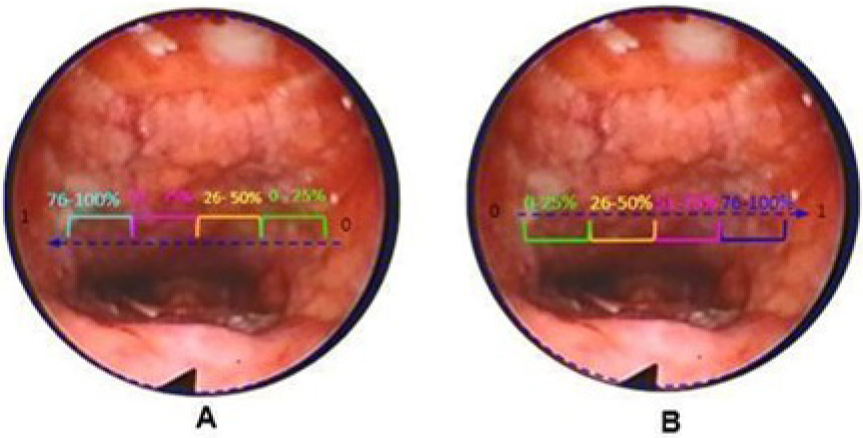


Figure 3. View of the velopharynx at rest. A) '#1' represents the right pharyngeal wall at rest, while '#0' indicates the resting position of the left pharyngeal wall. Considering the total space, the green line shows the maximum displacement of the left pharyngeal wall within 0-25%, the yellow line within 26-50%, the pink line within 51-75%, and the turquoise line within 76-100%. B) '#1' represents the left pharyngeal wall at rest, while '#0' indicates the resting position of the right pharyngeal wall. Considering the total space, the green line represents the maximum displacement of the right pharyngeal wall within 0-25%, the yellow line within 26-50%, the pink line within 51-75%, and the turquoise line within 76-100%.

c) Antagonistic movement of the lateral pharyngeal walls: This movement was identified when one or both walls moved away from the midline during the assessed emissions. The presence of antagonistic movement did not exclude the possibility of the lateral walls moving towards the midline in other emissions (Figure 4).

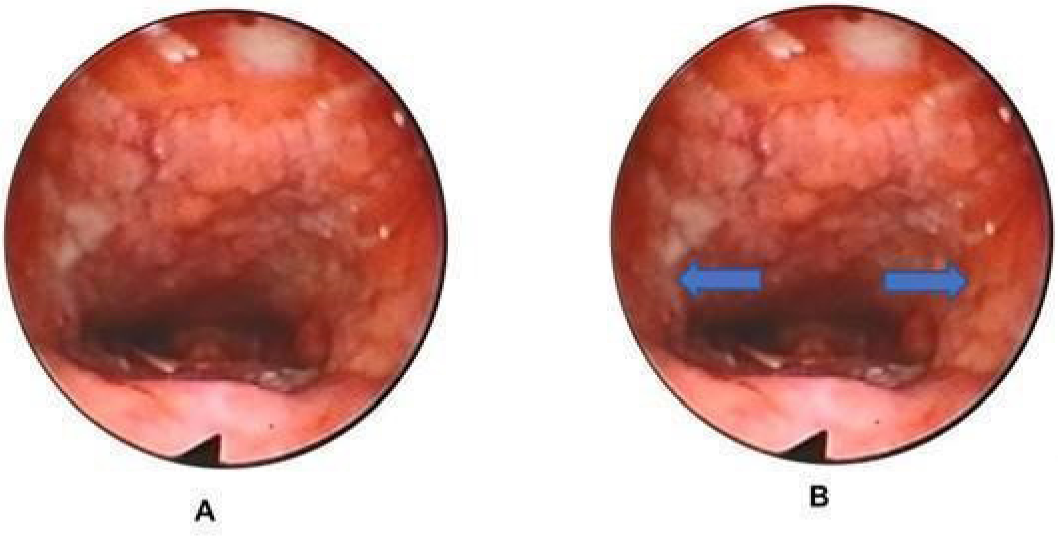


Figure 4. A) View of the velopharynx at rest. B) The arrows illustrate antagonistic movement, where one or both pharyngeal walls move away from the midline, during speech production.

d) Movement of the posterior pharyngeal wall: The wall at rest was fixed at a value of 0, the soft palate at rest was fixed at a value of 1, and the center of the velopharyngeal mechanism at rest was fixed at a value of 0.5. According to the protocol, the maximum displacement of the posterior pharyngeal wall could fall into one of the four categories: 0-25%, 26-50%, 51-75%, or 76-100% (Figure 5).

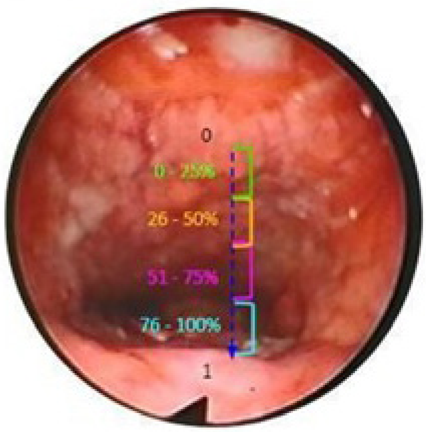


Figure 5. View of the velopharynx at rest. '#1' represents the velum at rest, while '0' denotes the resting position of the posterior pharyngeal wall. Considering the total space, the green line indicates the maximum displacement of the posterior pharyngeal wall within 0-25%, the yellow line within 26-50%, the pink line within 51-75%, and the turquoise line within 76-100%.

e) Passavant's ridge: The presence or absence of the Passavant's ridge should be identified (Figure 6).

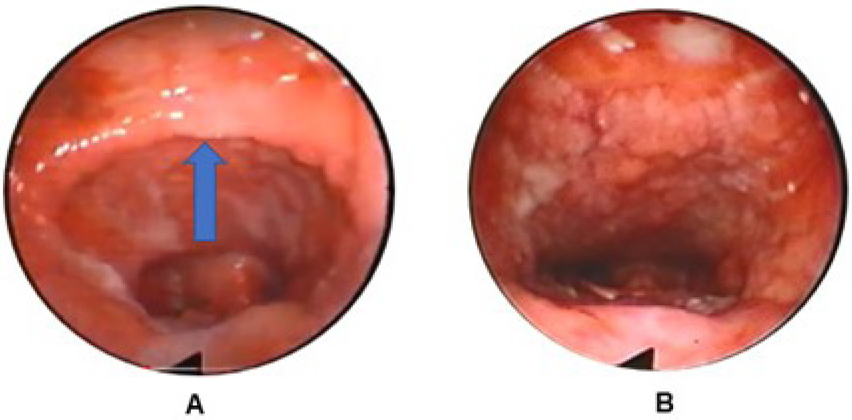


Figure 6. A) View of the velopharynx during speech showing the presence of Passavant's ridge. B) View of the velopharynx in the absence of Passavant's ridge.

f) Size of the velopharyngeal gap: SLPs were required to quantify the size of the velopharyngeal gap using reference measurements. This involved assessing the remaining gap after the maximum displacement of the velopharyngeal structures, rather than the extent of their movement. To achieve this, they compared the resting image with the image showing maximum displacement. If no movement was observed (i.e., the resting image was identical to the image at maximum displacement), the gap was quantified as 100%. The reference measurements were divided into a six-point scale: 0% = complete closure; 10% = gap with an air bubble; 25% = small gap; 50% = medium gap; 75% = large gap; 100% = very large gap (Figure 7).

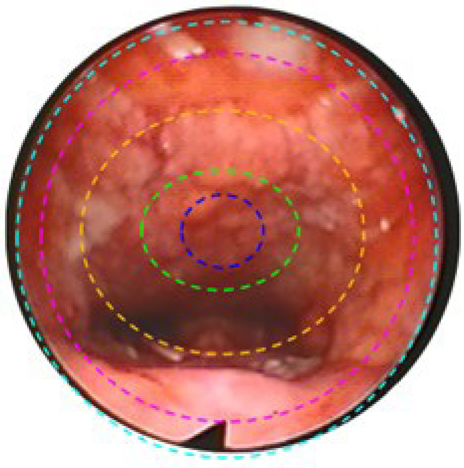


Figure 7. View of the velopharynx at rest. Considering the total space, the blue line represents a 10% gap, the green line represents a 25% gap, the yellow line represents a 50% gap, the pink line represents a 75% gap, and the turquoise line represents a 100% gap.

g) Type of velopharyngeal gap: The gap type was classified according to the proposal[17] as follows: sagittal (predominant movement in the lateral pharyngeal walls compared to other structures); coronal or transverse (predominant movement in the soft palate, which moves backward toward the posterior pharyngeal wall); circular (homogeneous participation of both the soft palate and the lateral pharyngeal walls); and circular with Passavant's ridge (a circular pattern accompanied by the formation of Passavant's ridge on the posterior pharyngeal wall) (Figure 8).

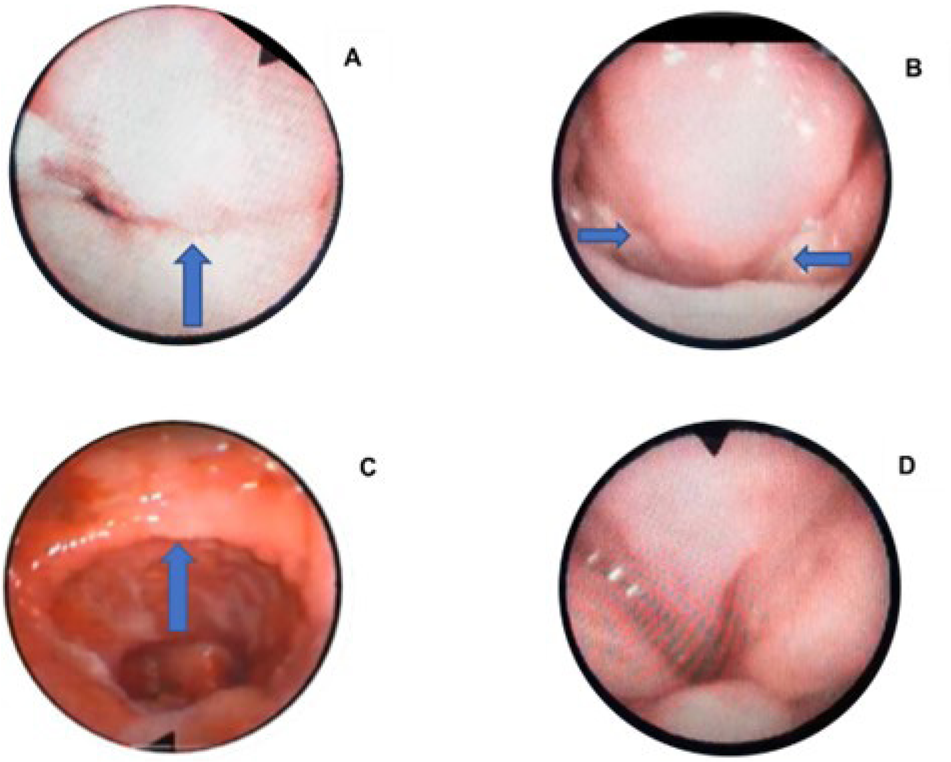


Figure 8. According to the type of velopharyngeal gap, A) shows a coronal or transverse gap, B) shows a sagittal gap, C) shows a circular gap with Passavant's ridge, and D) shows a circular gap.

Statistical Analysis

The results of the evaluations conducted by the SLPs – covering aspects such as the displacement of the soft palate and the pharyngeal walls (left, right, and posterior), the occurrence of antagonistic movement of the lateral walls and Passavant's ridge, and the size and type of the velopharyngeal gap - were analyzed using mean, standard deviation, median, and percentage.

To analyze intra-rater reliability, 20% of the recordings of the same samples were randomly selected, totaling 33 videos. The Kappa statistics was used to calculate the percentage of agreement.

1. Intra-rater agreement analysis: Cohen's Kappa statistics was used to assess agreement for: a) measurements of soft palate movement, posterior pharyngeal wall movement, and movement of the right and left lateral pharyngeal walls; b) the presence of Passavant's ridge; and c) the occurrence of antagonistic movement in the right and left lateral pharyngeal walls.
2. Measurements of soft palate and pharyngeal wall displacement (lateral and posterior) and gap type classification: Fleiss' Kappa statistic was used for these analyses.

The interpretation of the Kappa coefficients[18] followed the categorization proposed by Landis and Koch[19]:

- Poor: Kappa between 0.00 and 0.20
- Fair: Kappa between 0.21 and 0.40
- Moderate: Kappa between 0.41 and 0.60
- Substantial: Kappa between 0.61 and 0.80
- Almost perfect: Kappa between 0.81 and 1.00

For assessing agreement in measuring the size of the gap, the intra-class correlation coefficient (ICC) was used.

RESULTS

This study included video recordings from nasoendoscopies performed during the molding of the pharyngeal bulb for 28 subjects (100%), consisting of 10 males (35%) and 18 females (65%), aged 18 to 45 years (mean age 29, SD 8 years). Regarding cleft type, 14 subjects (50%) had cleft lip and palate, while the remaining 14 (50%) had cleft palate only.

Data Analysis

The analysis of the eight aspects assessed by the SLPs across all 28 (100%) exams revealed the following:

a) Amount of movement of velopharyngeal structures (soft palate and pharyngeal walls): The mean and median values indicated that displacement predominantly fell within the 0-25% range.
b) Occurrence of antagonistic movement of the lateral walls: 23 subjects (82%) did not exhibit antagonistic movement, while 5 subjects (18%) did.
c) Occurrence of Passavant's ridge: 21 subjects (75%) did not show Passavant's ridge, whereas 7 subjects (25%) did.
d) Size of the velopharyngeal gap: The mean and median values indicated a large gap size averaging 75%. No subject exhibited complete velopharyngeal closure or a minimal gap. Specifically, 1 subject (4%) had a small gap, 4 (14%) had a medium gap, 12 (43%) had a large gap, and 11 (39%) had a very large gap.
e) Type of velopharyngeal gap: 16 subjects (57%) exhibited a circular gap, 8 (28%) had a circular gap with Passavant's ridge, 1 (4%) had a sagittal gap, and 3 (11%) had a coronal gap.

Agreement

The intra-rater agreement percentages were considered almost perfect (100%) for all analyzed aspects: movement of the soft palate, right and left lateral pharyngeal walls, posterior pharyngeal wall, antagonistic movement of the lateral walls, Passavant's ridge, and gap type (Cohen's Kappa and Fleiss' Kappa = 1.0). The median size of the velopharyngeal gap was 75%, indicating a large gap. Inter-rater agreement (ICC) was also 100%.

Table 1 shows the distribution of results for: the displacement of the soft palate and the lateral and posterior pharyngeal walls; the occurrence of antagonistic movement and Passavant's ridge; and the size and type of the velopharyngeal gap.

Table 1. Distribution of subjects by movement of velopharyngeal structures, type and size of the gap

Subjects #	Gender	Cleft type	Velum mov	RPW mov	LPW mov	Post Wall mov	Antagonistic mov	Passavant's ridge	Gap size	Gap Type
1	F	CLP	0-25	0-25	0-25	0-25	N	N	6	Ci
2	M	CLP	0-25	0-25	0-25	0-25	N	N	5	Ci
3	F	CP	0-25	0-25	0-25	-	N	N	5	Ci
4	M	CLP	0-25	0-25	0-25	0-25	N	N	6	Ci
5	F	CP	0-25	0-25	0-25	0-25	N	N	5	CPR
6	M	CLP	0-25	0-25	0-25	-	N	N	5	Ci
7	F	CLP	-	0-25	0-25	-	Y	N	6	Ci
8	M	CLP	76-100	0-25	0-25	-	Y	N	3	Ci
9	M	CP	-	0-25	0-25	-	N	N	6	Sa
10	M	CLP	26-50	0-25	0-25	-	N	N	6	Ci
11	F	CP	0-25	26-50	26-50	-	N	N	5	Ci
12	F	CLP	0-25	26-50	26-50	26-50	N	Y	4	CPR
13	F	CP	0-25	0-25	0-25	0-25	N	Y	5	CPR
14	F	CP	0-25	0-25	0-25	-	N	N	6	Ci
15	F	CLP	0-25	26-50	26-50	0-25	N	Y	4	CPR
16	F	CLP	-	0-25	0-25	0-25	Y	Y	6	CPR
17	F	CLP	26-50	0-25	0-25	0-25	N	N	4	Co
18	M	CLP	26-50	0-25	0-25	-	N	N	6	Ci
19	F	CLP	0-25	0-25	0-25	-	Y	N	6	Ci
20	F	CP	0-25	0-25	0-25	0-25	N	N	6	Ci
21	M	CP	0-25	0-25	0-25	0-25	Y	Y	5	CPR
22	M	CLP	0-25	0-25	26-50	-	N	N	5	Co
23	F	CP	0-25	0-25	0-25	-	N	N	5	Co
24	F	CP	0-25	0-25	0-25	0-25	N	N	5	Ci
25	F	CLP	0-25	0-25	0-25	-	N	N	5	Ci
26	F	CP	26-50	26-50	26-50	26-50	N	Y	5	CPR
27	F	CP	0-25	0-25	0-25	-	N	N	6	Ci
28	M	CP	0-25	0-25	0-25	0-25	N	Y	5	CPR

Captions: Gender: F = Female; Cleft type (CLP = Cleft lip and palate; CP = Cleft palate); Mov = movement; RPW = right pharyngeal wall; LPW = left pharyngeal wall; PPW = posterior pharyngeal wall; Antagon = antagonistic (P = present; A = Absent).
Gap size: #1 represents a velopharyngeal closure (0%), #2 represents a minimal velopharyngeal gap with an air bubble (10%), #3 represents a small velopharyngeal gap (25%), #4 represents a medium velopharyngeal gap (50%), #5 represents a large velopharyngeal gap (75%), and #6 represents a very large velopharyngeal gap (100%).
Gap Type (Ci = Circular; CPR = Circular with Passavant's ridge; SA = Sagittal; Co = Coronal).

DISCUSSION

The most common characteristics observed in this study´s sample were minimal displacement of the velum and the lateral pharyngeal walls, along with large velopharyngeal gaps compared to their size at rest. These findings align with the concept of velopharyngeal hypodynamism, even during the best attempts to move the lateral pharyngeal walls. The cause of this hypodynamism remains unclear. Researchers suggest it may result from inadequate sensory stimulation during the passage of acoustic energy through the pharynx or the habitual practice of maintaining subglottic and intraoral pressure during speech, which could limit velopharyngeal movement.

Some studies refer to this hypodynamic phenomenon as a “black hole”, characterized by a dark pharynx due to the lack or absence of reflected light during phonation[8,10]. This large velopharyngeal gap can lead to changes in resonance and articulation, often resulting in the use of atypical points (compensatory articulation) to address the altered velopharyngeal movement[20,21].

The present study did not account for the presence and influence of compensatory mechanisms on the functioning of velopharyngeal structures, which is a limitation. The literature suggests that compensatory articulation can impact the degree of movement in the pharyngeal walls, thereby affecting the velopharyngeal activity pattern[22-24]. Consequently, individuals with compensatory articulation might rely less on the movement of the pharyngeal walls during speech, potentially explaining the observed limited movement. Therefore, perceptual-auditory evaluation should be the primary method for identifying speech alterations, as it is considered the "gold standard" for diagnosing VPD[22-24]. Since this study focused solely on characterizing velopharyngeal function through nasoendoscopic findings, data on compensatory articulations were not collected. Future research should combine perceptual-auditory evaluations with instrumental assessments to better investigate and characterize compensatory articulation in hypodynamic velopharynxes.

Another finding was the presence of antagonistic movement in the lateral pharyngeal walls during speech. This atypical behavior has been observed in individuals with cleft palate using pharyngeal bulb prostheses[9]. Although the exact cause of this movement pattern is not well understood, it is believed to result from the bulb´s presence in the pharynx, which causes the pharyngeal walls to move away from the bulb rather than towards it. In this study, this unusual movement was detectable through nasoendoscopy, even without the bulb present in the pharynx at the time of analysis. A related study involving individuals with repaired cleft palates who used pharyngeal bulbs found that oronasal balance during speech worsened following intensive speech therapy. Researchers attributed this decline to the presence of antagonistic movement when the bulb was used. They recommend that future research should explore whether intensive speech therapy programs might exacerbate this antagonistic behavior in the lateral pharyngeal walls[12].

The hypodynamic performance of the velopharynx, coupled with learning errors involving antagonistic movement, poses a significant challenge for multidisciplinary teams in determining the optimal treatment approach[8-10]. Attempting to address a large velopharyngeal gap through surgery alone, without tackling the underlying hypodynamic condition, can lead to airway obstructions and may not improve resonance or eliminate nasal air emission[8-10]. In such cases, using a pharyngeal bulb in conjunction with an intensive speech therapy program can be a viable alternative for managing VPD. This approach aims to modify the hypodynamic pattern, potentially allowing the individual to undergo surgery with a better prognosis[9,12,13].

A study evaluated the effectiveness of using a pharyngeal bulb to eliminate hypernasality in 20 individuals with cleft palate and hypodynamic velopharynx. The results were not statistically significant, indicating that the pharyngeal bulb alone is insufficient to eliminate hypernasality in these cases. The authors suggested that the reasons for the prosthetic treatment´s failure are multifaceted. Factors such as functional and anatomical changes, including physiological and phonetic aspects, variations in cleft types, speech therapy interventions, and alterations in the dental arch, may contribute to the pharyngeal bulb´s effectiveness. The objective of this study was not to characterize the functioning pattern of hypodynamism in the presence of a pharyngeal bulb.

Most studies report on surgical and prosthetic treatment of VPD but do not address the presence of a hypodynamic velopharynx[1,2,7,11]. Therefore, further research on hypodynamic velopharynx is necessary to enhance the management and treatment of this dysfunction.

CONCLUSION

Subjects presented with VPD indicative of a hypodynamic velopharynx exhibited a velopharyngeal gap equal to or greater than 50% of the resting size of the velopharyngeal space, with minimal movement of the soft palate and pharyngeal walls.

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Authors contributions:

CMS: Data curation; Formal analysis; Investigation; Writing - Original draft, Writing - Review and editing.

MIPK: Conceptualization; Methodology; Project administration; Supervision; Writing - Review and editing.

JCRD: Conceptualization; Methodology.

Data sharing statements:

The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research supporting data is not available.