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## Examining Velopharyngeal Closure Patterns based on Anatomic Variables

**Holly Nelson Jordan, MS,**

Speech-Language Pathologist, Dept. of Communication Sciences & Disorders, East Carolina University

**Graham C. Schenck, MS,**

Doctoral Candidate, Dept. of Communication Sciences & Disorders, East Carolina University

**Charles Ellis, PhD,**

Associate Professor, Dept. of Communication Sciences & Disorders, East Carolina University

**Balaji Rangarathnam, PhD,**

Assistant Professor, Dept. of Communication Sciences & Disorders, East Carolina University

**Xiangming Fang, PhD,** and

Associate Professor, Dept. of Biostatistics, East Carolina University

**Jamie L. Perry, PhD**

Associate Professor, Dept. of Communication Sciences & Disorders, East Carolina University

### Abstract

The purpose of this study was to utilize three-dimensional magnetic resonance imaging (MRI) to correlate velopharyngeal closure patterns with velopharyngeal anatomical structural characteristics. Thirty-eight participants (18 females and 20 males) between 19 and 32 years of age participated in the study. Participants were evaluated using MRI and nasopharyngoscopy to determine closure pattern type and their relationship to anatomical characteristics believed to influence velopharyngeal closure. Structural anatomical measures were completed in the vertical (nasopharyngeal length) and horizontal (nasopharyngeal width) planes. Anterior to posterior dimensions of pharyngeal depth, posterior pharyngeal wall thickness, velar length, effective velar length, and adenoid thickness were also completed. Velar length and adenoid thickness varied based on closure patterns, with coronal closure pattern demonstrating significantly larger values compared to circular closure pattern. There were no statistically significant differences for effective velar length, pharyngeal depth, nasopharyngeal length, posterior pharyngeal wall thickness, and nasopharyngeal width based on the type of closure pattern. Closure patterns varied by gender, with females demonstrating more circular closure patterns compared to males who demonstrated more coronal closure patterns. Nasopharyngeal length, velar length, and nasopharyngeal width also varied by gender, with males demonstrating significantly larger values compared to females. Statistically significant differences were observed in velopharyngeal

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Corresponding Author: Graham C. Schenck, PhD, Department of Rehabilitation Therapies, Gillette Children's Specialty Healthcare, 200 University Avenue East, St. Paul, MN 55101; GrahamCSchenck@gillettechildrens.com.

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anatomical structural measures and gender during evaluations of closure patterns. These preliminary findings indicate the length of the velum and thickness of the adenoids may have the greatest impact on velopharyngeal closure patterns.

### Keywords

velopharyngeal dysfunction; closure pattern; magnetic resonance imaging

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## INTRODUCTION

A substantial body of literature exists exploring velopharyngeal closure patterns among individuals with normal velopharyngeal anatomy. Finkelstein et al<sup>1</sup> and Croft et al<sup>2</sup> found coronal closure patterns in 51.7% to 55% of participants with normal velopharyngeal anatomy. Circular closure patterns were present in 23.3% of participants.<sup>1</sup> Circular with Passavant's ridge closure patterns were observed in 19% of participants with normal velopharyngeal anatomy and were found to be the second most common closure pattern.<sup>2</sup> Finkelstein et al<sup>1</sup> found a 1% prevalence of sagittal closure patterns in participants with normal velopharyngeal anatomy. In contrast, Croft et al<sup>2</sup> observed sagittal closure patterns in 16% of participants with normal velopharyngeal anatomy. In summary, studies suggest high variability in closure patterns even among individuals with normal anatomy.

Studies have examined whether an individual's closure pattern is based on the individual's anatomic parameters.<sup>1,3,4</sup> These studies hypothesize that velopharyngeal closure patterns are a result of particular anatomic parameters. Closure patterns could be determined based on a set of anatomic features unique to each respective closure pattern. For example, the coronal closure pattern is related to a wide and flat oropharynx, increased transverse pharyngeal diameter, decreased posterior pharyngeal wall thickness, and a shorter anteroposterior diameter (posterior nasal spine to the posterior pharyngeal wall) compared to other closure patterns.<sup>1,3,4</sup> The circular closure patterns are associated with medial movement of the pharyngeal walls and a deep oropharynx.<sup>1,3,4</sup> A greater anteroposterior pharyngeal diameter, shorter transverse pharyngeal diameter, and a slope in the lateral pharyngeal walls toward the posterior pharyngeal walls are also observed in circular closure patterns.<sup>1,3,4</sup> Finally, a soft tissue pad can be observed anterior to the tubercle of the atlas in patients with a Passavant's ridge.<sup>1,3,4</sup>

Therefore, the present study was designed to examine potential correlations between velopharyngeal anatomical structural characteristics and closure patterns. This study utilized three-dimensional magnetic resonance imaging (MRI) to explore the relationships between the two parameters (anatomical structural characteristics and closure patterns). Because of observed differences in velopharyngeal structures between adult males and females,<sup>5</sup> the study also sought to examine gender differences in the type of closure pattern and the anatomical structural characteristics of the participants. The first hypothesis was that participants with coronal closure patterns would have longer velums and smaller nasopharyngeal length when compared to those with circular closure patterns. This was expected given the nature of closure would rely on greater anterior to posterior movement of

the velum compared to other closure patterns. The second hypothesis was that a smaller velar length, greater pharyngeal depth, and greater posterior pharyngeal wall thickness would be present among participants with a circular closure patterns given the reliance of closure on medial movement of all velopharyngeal structures (i.e., lateral pharyngeal walls, velar movement, and posterior pharyngeal wall). Finally, because adult males have been shown to have a significantly longer velum compared to females, it was expected that males would more likely exhibit coronal closure patterns compared to females.

## MATERIALS AND METHODS

This study was reviewed and approved by the East Carolina University Institutional Review Board (IRB).

### Participants

In accordance with the local institutional review board, 18 females between 19 and 32 years of age (mean = 22.38; SD = 3.42) and 20 males between 18 and 32 years of age (mean = 22.35; SD = 3.70) were recruited to participate in the study. Flyers posted in the community were used to recruit potential participants. Participants reported no history of craniofacial anomalies, sleep apnea, swallowing disorders, or neurological disorders that would affect measures of structures or their movement.

### Baseline Examinations

The participants were perceptually judged by a speech-language pathologist with over 15 years of experience in evaluating resonance disorders using a 5-point rating scale to confirm normal nasalance (rating of “0”). An oral mechanism examination and participant report was used to confirm participants were free of structural defects. Body mass index (measured as body fat based on weight and height) was assessed to determine if the participants would be able to fit into the MRI bore and to control for pharyngeal variations related to obesity.<sup>6,7</sup>

### Nasendoscopy

Flexible nasopharyngoscopy was used following standard clinical procedures to determine the velopharyngeal closure pattern. Specifically, the nose was decongested bilaterally using Rhinall and then anesthetized with Lidocaine. The scope was passed through the middle meatus of the most patent nostril and positioned above the velopharyngeal port. The participants were instructed to repeat high and low pressure oral and nasal speech sounds in words, sentences, and connected speech to assess closure patterns. The closure patterns were determined using a blind-rating system performed by two judges (i.e., speech-language pathologists with experience reviewing nasendoscopy). Judges familiarized themselves with the Golding-Kushner<sup>8</sup> and Finkelstein et al<sup>1</sup> rating scales and then practiced while watching together a separate sample of scope videos.

Both raters completed training together by watching nasopharyngoscopy video recordings from participants not included in this study. The raters discussed the videos and used published definitions based on amount of structural movement<sup>1,4</sup> for determining closure type. The training session included 10 videos among the varied closure types, with the

exception of circular with Passavant's ridge because no samples of this closure pattern type were available. The raters discussed any cases where disagreement occurred and came to an agreement on the method of classification. Following the training period, both raters independently rated the videos to establish inter-rater reliability for identifying the closure patterns among participants. The two raters agreed on all ratings of closure pattern. Participants were categorized based on their closure pattern.

### **Magnetic Resonance Imaging**

A Siemens 3 Tesla Trio (Erlangen, Germany) three-dimensional MRI scanner was used to collect the data. An elastic wrap was placed above the glabella and secured to the to the head coil to limit the head movement during the scanning process. The participant was in the supine position and instructed to remain at rest, resulting in the velum in a fully lowered position resting on the base of the tongue. A three-dimensional turbo-spin-echo (TSE) sequence called Sampling Perfection with Application optimized Contrasts using different flip angle Evolution (SPACE) was used to obtain a three-dimensional volume. This MRI protocol uses a non-Cartesian spiral sequence that is used for research analyses. A large field of view was used to cover the oropharyngeal and craniofacial anatomy ( $25.6 * 19.2 * 15.5 \text{ cm}^3$ ) with 0.8 mm isotropic resolution, 2500 ms repetition time, 268 ms (with echo train length of 171), 0.8 slice thickness, and with an acquisition time of slightly less than 5 minutes (4:52).

### **Image Analysis**

Raw data were imported to Amira 5.4.0 Visualization and Volume Modeling software (Visage Imaging GmbH, Berlin, Germany) to view the images and perform measures of velopharyngeal muscles and structures. The measurements were taken from two planes to demonstrate the anatomical features that can be observed in a three-dimensional image. From the sagittal plane, measures of velar length, effective velar length, pharyngeal depth, nasopharyngeal length, adenoid thickness, and posterior pharyngeal wall thickness were obtained. The axial plane was used to obtain a measure of nasopharyngeal width. Measures were selected to represent the three-dimensional anatomical parameters that may influence velopharyngeal closure. Additionally, these measures were selected to represent velopharyngeal measures in the vertical (nasopharyngeal length), horizontal (nasopharyngeal width), and anterior to posterior (pharyngeal depth, posterior pharyngeal wall thickness, velar length, effective velar length, and adenoid thickness) dimensions. These measures, described in Table 1 and shown in Figure 1, were selected and defined based on previous vocal tract and airway volumetric studies.

### **Statistical Analyses**

The measurements obtained through Amira 5.4.0 were analyzed using binomial logistic regression and descriptive analyses. Binomial logistic regression was performed because only two types of closure patterns were observed, as described in the results section. We also administered chi-square tests to analyze differences in categorical variables across gender. The seven different measurements obtained in Amira were examined to determine if differences were present between the demographic categories and closure patterns. Baseline descriptive analyses was used to examine the gender and closure pattern categories and

provided the mean, median, and standard deviation values from the above measurements. A binomial logistic regression was performed to predict velopharyngeal closure patterns based on the aforementioned anatomic parameters. It was hypothesized that the variations in the velopharyngeal anatomy measures would correspond with a coronal or circular closure pattern.

A primary rater and secondary rater with experience in MRI data processing in Amira 5.4.0 re-measured data from 15 randomly selected participants (40% of the participants) 4 months after the first measures were obtained. Pearson product moment was utilized to determine if there was a positive correlation between the measures obtained by the primary rater and secondary rater. The intrarater and interrater reliability ranged from  $r = .75$  to  $r = .99$  for the seven measures.

## RESULTS

Of the 38 participants, 20 participants (14 males and 6 females) displayed a coronal closure pattern while 18 participants (6 males and 12 females) displayed a circular closure pattern. Participants with a coronal closure pattern had a significantly greater (Table 2) velar length (mean = 37.67 mm) compared to those with a circular closure pattern (mean = 34.54 mm),  $p = .013$ .

Adenoid thickness was significantly greater (mean = 3.83 mm) among participants with coronal closure pattern compared to those with a circular closure pattern (mean = 1.57 mm),  $p = .004$ , using a binomial logistic regression. No statistically significant differences were noted for effective velar length, pharyngeal depth, nasopharyngeal length, posterior pharyngeal wall thickness, and nasopharyngeal width based on the type of closure pattern. Pharyngeal depth values were similar between those with a circular (mean = 25.12 mm) closure pattern compared to those with a coronal (mean = 24.51 mm) closure pattern. Nasopharyngeal length mean values were minimally (1.17 mm) greater for those with coronal closure pattern. Mean differences in the thickness of the posterior pharyngeal wall, effective velar length, and nasopharyngeal width measures were less than 0.67 mm between closure pattern types.

Given the reported variations in gender for velopharyngeal structures among adults,<sup>5</sup> we examined whether males or females showed differences in the type of closure pattern and/or anatomy of interest. A chi-square test for association demonstrated that females were more likely to have a circular closure pattern compared to males who were more likely to have a coronal closure pattern ( $p = .024$ ). Additionally, mean nasopharyngeal length for males (mean = 39.40 mm, median = 39.97 mm) was significantly greater than females (mean = 35.68 mm, median = 35.45 mm),  $p = .010$  (Table 3).

Mean velar length for males (mean = 37.79 mm, median = 37.52 mm) was significantly greater than females (mean = 34.41 mm, median = 34.24 mm),  $p = .007$ , using a binomial logistic regression analysis. Mean nasopharyngeal width for males (mean = 21.34 mm, median = 21.73 mm) was significantly larger than females (mean = 18.01 mm, median =

18.05 mm),  $p = .003$ . Although not significant, males displayed a greater effective velar length (mean = 13.85 mm; SD = 1.87) compared to females (mean = 12.68 mm; SD = 1.78).

## DISCUSSION

This study examined 38 adult participants to determine if anatomical variables correspond to a type of velopharyngeal closure pattern. The four key findings were (1) all participants exhibited one of only two closure pattern types; (2) velar length and adenoid thickness were the only anatomical structural characteristics that correlated with velopharyngeal closure pattern; (3) there were no significant correlations between pharyngeal depth, nasopharyngeal length and depth, effective velar length, thickness of the posterior pharyngeal wall and closure patterns; and (4) statistically significant gender differences were observed for nasopharyngeal length, velar length, and nasopharyngeal width. The first key finding was all participants exhibited one of two closure patterns. Fifty-three percent exhibited coronal closure patterns and 47% exhibited circular closure patterns. None of the participants in the present study displayed either a sagittal or circular with Passavant's ridge closure pattern. These findings were surprising as previous studies have reported a distribution of participants across different closure pattern types.<sup>1,2</sup>

Second, velar length and adenoid thickness were the only anatomical structural characteristics that correlated with velopharyngeal closure patterns. Although some individuals presented with greater adenoid thickness, we did not observe adenoid hypertrophy in any subjects based on objective and qualitative measures. Individuals with a coronal closure pattern were more likely to have a longer velum and greater adenoid thickness compared to those with circular closure patterns. These observations agree with Witzel and Posnick,<sup>12</sup> who also observed coronal closure patterns to be more prevalent in participants that have adenoid tissue compared to circular closure patterns. This is likely due to the closer positioning of the adenoid to the velum at rest, resulting in a shorter distance (velopharyngeal gap) to achieve velopharyngeal closure. Siegel-Sadewitz and Shprintzen<sup>13</sup> investigated the impact of adenoid involution on closure patterns in participants with normal velopharyngeal anatomy and participants with cleft palate. The authors observed changes in the closure pattern in 50% of the participants post adenoid involution. However, the participants that demonstrated a coronal closure pattern (7 out of 30) continued to have the same closure pattern after adenoid involution.<sup>13</sup> No participants in the present study reported a history of adenoidectomy. Findings suggest that coronal closure patterns may continue to persist through adulthood even after involution of adenoid tissue. Additional research quantifying the amount of adenoid involution and the subsequent effects on velopharyngeal closure patterns is warranted in individuals with clinically normal anatomy and those with disordered anatomy.

Longitudinal or cross-sectional design studies are needed to assess age-related changes to the adenoid tissue and subsequent velopharyngeal portal adaptations. Handelman and Osborne<sup>14</sup> assessed longitudinal growth of the adenoid tissue and other facial landmarks in 12 children from the ages of 9 months to 18 years. A consistent trend of minimal adenoid presence at age 1, hypertrophy evident by 2 years of age, maximum hypertrophy during the early school years, and involution during adolescence was observed. However, the authors



did not assess velopharyngeal closure patterns or related changes as a result of age. Siegel-Sadewitz and Shprintzen<sup>13</sup> demonstrated that velopharyngeal insufficiency (VPI) did not develop in 20 children (10 with normal anatomy, 5 with repaired cleft palate, 5 with unrepaired submucous cleft palate) with normal speech as a result of adenoid involution. The authors also demonstrated reduced lateral pharyngeal wall movement from pre- to post-pubertal life in all 10 children with normal anatomy and 3 children with cleft palate. These findings suggest a potential adaptation effect of the velopharyngeal port as a result of age-related anatomical changes (e.g., adenoid involution, reduced pharyngeal wall movement). More specifically, regardless of etiology, children with normal speech that has been reinforced throughout the pre-pubertal years may be capable of making physiologic adjustments to compensate for anatomic changes post-puberty.<sup>13</sup> However, these findings do not account for sudden changes to the adenoid tissue that may result from partial or complete adenoidectomy. It may be hypothesized that sudden changes to the adenoid tissue in individuals in the present study with greater adenoid thickness measures may have resulted in VPI characterized by hypernasal speech. Future studies should assess changes to the velopharyngeal mechanism as a result of age and surgical procedures (e.g., adenoidectomy) with larger sample sizes, and consider inclusion of adult and pediatric populations with different etiologies.

The third key finding demonstrated no significant correlations between pharyngeal depth, nasopharyngeal length and depth, effective velar length, thickness of the posterior pharyngeal wall and velopharyngeal closure patterns. These findings differ from studies by Finkelstein et al<sup>1,3,4</sup> who utilized two-dimensional images and identified relationships between anatomic characteristics and closure patterns. For example, participants with coronal closure patterns exhibited a wide and flat oropharynx, decreased posterior pharyngeal wall thickness, increased transverse pharyngeal diameter, and a shorter anteroposterior diameter. Those with circular closure patterns presented with characteristics such as a deep oropharynx, shorter transverse pharyngeal diameter, and a greater anteroposterior pharyngeal diameter.

The fourth finding from the present study identified statistically significant gender differences for nasopharyngeal length, velar length, and nasopharyngeal width. Males were more likely to display a coronal closure pattern whereas females were more likely to display a circular closure pattern. This difference may be explained by the greater velar length found in males that also corresponded with coronal closure patterns. Males demonstrated a significantly greater mean velar length than females. More importantly, these findings may reflect a larger effective velar length in males, as found in the present study. To support this notion, Perry et al<sup>5</sup> demonstrated increased velar length in males compared to females. In the present study, velar lengths (mean= 37.79 mm; SD= 3.40 mm) were similar to those reported by Perry et al<sup>5</sup> (mean= 36.9 mm; SD= 4.9) and Perry et al<sup>15</sup> (mean= 37.6 mm; SD=3.2 mm). However, these findings differ from those reported by Bae et al<sup>16</sup> who demonstrated increased velar length for females compared to males. Bae et al<sup>16</sup> examined 10 Caucasian adults (5 males and 5 females). Differences in sample sizes among the three studies may contribute to the variations in findings.

In the present study, male participants also exhibited significantly larger average nasopharyngeal lengths compared to females. The findings reported in this study agree with the findings of Vorperian et al,<sup>11</sup> where females exhibited smaller nasopharyngeal length when compared to males who were 16 years of age or older. Gender differences were also noted for nasopharyngeal width, with males exhibiting a significantly larger mean nasopharyngeal width compared to females. Tian et al<sup>10</sup> measured nasopharyngeal width and revealed a similar mean value for adults. Although findings by Tian et al<sup>10</sup> were not reported by gender; the mean value for adults was 20.46 mm for nasopharyngeal width, which is similar to findings observed in this study.

Differences in velopharyngeal structure and function in adults with clinically normal anatomy observed in the present study may be applicable to populations with clinically disordered anatomy. Studies suggest 25–35% of children with cleft palate will develop VPI as evidenced by hypernasal speech following initial palatal repair.<sup>17,18</sup> These children often require an additional surgery for the correction of hypernasal speech. As such, a thorough evaluation of a patient's velopharyngeal anatomy and closure pattern characteristics is necessary to select appropriate surgical procedures (e.g., Furlow double-opposing Z-plasty, sphincterpharyngoplasty) and customize the procedure for optimal speech outcomes. In the present study, males were more likely to present with a coronal closure pattern, and also demonstrated increased velar length compared to females. Females were more likely to present with a circular closure pattern than males. These findings demonstrate sex differences in velopharyngeal anatomy and closure that may be useful in selection of secondary surgery types for individuals with repaired cleft palate and VPI. Additional anatomical factors beyond closure pattern and velar length must also be taken into consideration when selecting a surgical procedure for VPI. Additional studies are needed to determine if findings in adults with clinically normal anatomy are transferrable to pediatric populations, especially those with clinically disordered anatomy such as cleft palate.

Although the findings reported here are unique and informative, they are not without limitations. The relatively small sample size and the observation and evaluation of only two velopharyngeal closure types limit interpretations to the general population. It is possible that the small sample size utilized in this study created limitations in the possible number of closure patterns observed. Future studies should utilize larger sample sizes and consider inclusion of all closure pattern types. This study aimed to provide pilot data among an adult population. However, the clinical population of interest is young children with repaired cleft palate. This study did not examine this clinically relevant age group, however, methods could be similarly applied to the child population in future investigations. Due to the small sample size, measurement error may also negatively affect the outcomes. Although reliability was acceptable, increasing sample size may improve measurement accuracy in defining boundaries for anatomic landmarks. We feel that this study represents a significant contribution to the body of literature on velopharyngeal closure pattern characteristics in individuals with normal velopharyngeal anatomy. Findings from the present study provide normative data that may be useful for comparisons to individuals with disordered anatomy in future studies.



## CONCLUSION

The findings of this study suggest at least two closure patterns correlate with specific anatomical structural characteristics. Participants with a coronal closure pattern were more likely to have a longer velum and greater adenoid thickness compared to those with a circular pattern of closure. Additionally, this study suggests gender differences in velopharyngeal closure patterns, with males more likely to have a coronal closure pattern compared to females. This is likely due to the increased velar length observed in males compared to females. The present study also revealed gender differences in nasopharyngeal length, velar length, and nasopharyngeal width. The results of the study serve as preliminary data to suggest that the length of the velum and thickness of the adenoids may be of significance in understanding closure pattern types. This may be of clinical importance when examining clinical populations such as cleft palate and considering surgical approaches that impact velar length and/or adenoid volume.

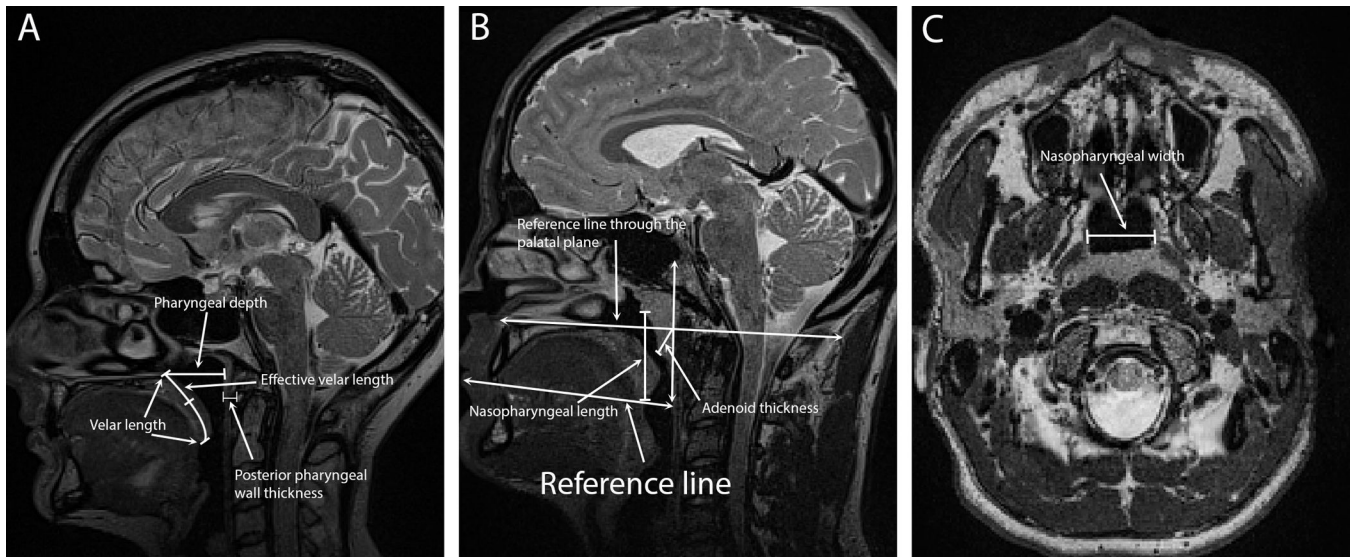
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**Figure 1.** Measures of velar length, effective velar length, pharyngeal depth and posterior pharyngeal wall thickness assessed in the midsagittal image plane (A); nasopharyngeal length and adenoid thickness assessed in the midsagittal image plane (B); nasopharyngeal width assessed in the axial image plane (C).

**Table 1**

## Description of the velopharyngeal measurements

McCarthy, Coccaro & Schwartz, 1979	Velar length	Distance from the tip of the velum to the nasal surface of the posterior nasal spine.
Tian et al. 2010	Effective velar length	Distance between the posterior border of the hard palate and the center of the palatal muscle at rest.
McCarthy, Coccaro & Schwartz, 1979	Pharyngeal depth	Distance from the posterior nasal spine to the posterior pharyngeal wall.
Vorperian et al. 2009	Nasopharyngeal length	A reference line was drawn from the lower lip to the posterior pharyngeal wall then the measurement started from the inferior tip of the uvula to the superior border of the nasopharynx.
Tian et al. 2010	Nasopharyngeal width	Widest horizontal distance between the two lateral pharyngeal walls on the horizontal plane at rest. A reference line was drawn through the palatal plane on the sagittal image then flipped to an axial image.
	Thickness of the posterior pharyngeal wall	Posterior pharyngeal wall to the anterior arch of C1.
	Adenoid thickness	A horizontal reference line was drawn through the palatal plane and a vertical reference line was drawn along the anterior border of the posterior pharyngeal wall. The adenoid width was then measured from a 45 degree angle to the end of the adenoid pad.

Velopharyngeal measures (reported in mm) and results of a descriptive analysis and binomial logistic regression comparing circular and coronal closure patterns

**Table 2**

Measure	Circular (n = 18) (Mean ± SD)	Coronal (n = 20) (Mean ± SD)	Circular (Median)	Coronal (Median)	P Value
Pharyngeal depth	25.12 ± 2.43	24.51 ± 3.34	25.25	25.38	.514
Nasopharyngeal length	37.02 ± 4.52	38.19 ± 4.54	37.50	38.10	.418
Thickness of PPW	8.61 ± 1.77	9.28 ± 1.91	8.61	9.15	.256
Effective velar length	13.01 ± 2.05	13.55 ± 1.76	13.06	13.25	.372
Velar length	34.54 ± 3.34	37.67 ± 3.89	35.52	37.46	.013
Nasopharyngeal width	19.53 ± 3.08	19.97 ± 3.97	19.60	20.88	.701
Adenoid thickness	1.57 ± 2.15	3.83 ± 2.28	0	3.92	.004

Abbreviation: PPW, posterior pharyngeal wall; mm, millimeter; SD, standard deviation

Velopharyngeal measures (reported in mm) and results of a descriptive analysis and binomial logistic regression comparing male and female participants

**Table 3**

Measure	Male (n = 20) (Mean ± SD)	Female (n = 18) (Mean ± SD)	Male (Median)	Female (Median)	P Value
Pharyngeal depth	24.69 ± 3.20	24.93 ± 2.67	25.15	25.50	.804
Nasopharyngeal length	39.40 ± 4.61	35.68 ± 3.57	39.97	35.45	.010
Thickness of PPW	9.39 ± 2.08	8.49 ± 1.46	9.31	8.61	.127
Effective velar length	13.85 ± 1.87	12.68 ± 1.78	13.50	12.90	.053
Velar length	37.79 ± 3.40	34.41 ± 3.78	37.52	34.24	.007
Nasopharyngeal width	21.34 ± 3.01	18.01 ± 3.30	21.73	18.05	.003
Adenoid thickness	2.73 ± 2.33	2.79 ± 2.69	2.84	3.15	.940

Abbreviation: PPW, posterior pharyngeal wall; mm, millimeter; SD, standard deviation