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Evaluation of the Symmetry of the Levator Veli Palatini Muscle and Velopharyngeal Closure Among a Noncleft Adult Population

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Abstract

Purpose: The goal of this study is to determine the typical range of asymmetry between the length and thickness of the levator veli palatini muscle and to explore the impact of the observed asymmetry on velopharyngeal closure. A second objective is to report normative length and thickness of the levator veli palatini muscle among adults with typical velopharyngeal anatomy.

Method: Magnetic resonance imaging (MRI) data and Amira 5.5 Visualization software were used to evaluate the levator veli palatini muscle among 89 participants with typical velopharyngeal anatomy. Flexible nasopharyngoscopy was used to determine the function of velopharyngeal closure among 39 of the 89 participants with typical velopharyngeal anatomy to examine the functional impact of observed asymmetry.

Results: Matched paired *t* tests demonstrated a nonsignificant difference between the length and thickness of the right and left levator muscle. The mean difference between the right and left length of the levator muscle was 2.28 mm but ranged from 0.09 mm to 10.37 mm. In all cases where individuals displayed asymmetry in the levator muscle through MRI, there was no observed impact on the symmetry of velopharyngeal closure.

Discussion: This study suggest that differences in the right and left levator veli palatini muscle are not significant among individuals without cleft palate. However, among individual cases where asymmetry was sizeable, there was no direct impact on the closure pattern. This may suggest there are multiple factors that contribute to asymmetrical velopharyngeal closure that are beyond the level of the levator veli palatini muscle.

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Keywords

levator veli palatini muscle; symmetry

Introduction

The velopharyngeal (VP) mechanism includes the levator veli palatini (levator), superior constrictor, palatoglossus, palatopharyngeus, salpingopharyngeus, musculus uvulae, and tensor veli palatini muscles (Kummer, 2013). The levator muscle is the primary muscle for velar elevation. Understanding the typical morphology of the levator muscle is critical for improving knowledge about atypical VP mechanisms such as that among individuals with cleft palate and hypernasal speech. Inouye et al. (2015) used computational modeling to predict the effects of altering different VP anatomical variables on VP function by using magnetic resonance imaging (MRI) data from 10 adult participants. The results highlighted that the anterior-to-posterior distance of the VP port, cross-sectional area of the levator muscle, and extravelar length of the levator muscle are the most influential anatomic parameters for establishing normal VP function. These findings suggest that any variation in the levator muscle length, thickness, or VP portal depth likely contribute to VP dysfunction.

Numerous studies have reported the levator muscle dimensions; however, authors often report a single mean value for the right and left levator muscle length and thickness (Azzam and Kuehn, 1977; Kuehn and Azzam, 1978; Huang et al., 1997; Ettema et al., 2002; Tian et al., 2010; Perry et al., 2011; Perry et al., 2013; Kotlarek et al., 2017). Perry et al. (2011) and Perry et al. (2013) reported differences between the right and left length of the levator muscle bundles to be 1.1 mm and 2.9 mm among 2 infants and 10 adults with typical VP anatomy, respectively. Huang et al. (1997) observed 0.02 mm difference in the right and left levator muscle thickness among 15 cadaver specimens with typical VP anatomy. Kotlarek et al. (2020) observed 0.11 mm difference between the right and left levator muscle thickness among 5 children with typical VP anatomy. Collectively, these studies demonstrate minimal asymmetry between the length and thickness of the levator muscle bundles in typical anatomy and in cleft anatomy. However, these studies represent relatively small sample sizes (less than 10 participants per group for in vivo studies).

Park et al. (2015) used MRI to examine the differences between the right and left levator thickness among 17 patients with velocardiofacial syndrome (VCFS) and compared results to 9 patients with submucous cleft palate without VCFS. The results demonstrated asymmetric thickness between the right and left levator muscle bundles for both groups. However, data were not compared to a nonsyndromic non-cleft study group to determine whether the amount of asymmetry observed among those with VCFS is significantly greater than that observed in typical VP anatomy and physiology. Chegar et al. (2006) used videofluoroscopy and nasopharyngoscopy to compare the velum, pharynx, and larynx among 121 participants with VCFS to 20 participants with typical anatomy. The results demonstrated that 67% of participants with VCFS had asymmetric elevation of the velum during speech where the right side of the velum was elevated higher during VP function for speech. In addition, 66% of participants with VCFS had hypoplasia on the left side of the velum. It is unclear if the asymmetry in VP closure observed by Chegar et al. (2006) is related to levator muscle asymmetry, as suggested by Park et al. (2015).

Having insight into muscle structure and function in typical population is critical in providing future comparison with participants with VCFS. More specifically, it is not clear what degree of asymmetry of the right and left levator muscle length and thickness is considered "typical" in typical population; that is, what degree of asymmetry of the right and left levator muscle length and thickness has a negligible effect on VP function during normal speech? Furthermore, it is not known whether asymmetric features of the levator muscle bundles result in an observable impact on VP function among individuals with normal speech. In addition, because sample sizes of previous studies on population with typical VP anatomy were less than 10, studies did not control for the effect of sex, which is a known factor to impact VP structures (Perry et al., 2016).

The purpose of this study was to determine whether asymmetry between the right and left length and thickness of the levator muscle bundles is observed among individuals with typical VP anatomy and typical speech. The second aim was to examine whether the levator muscle asymmetry results in observable asymmetry in the VP closure. Within this study, we also aimed to expand the literature by reporting normative data of the right and left levator muscle bundles according to sex groups. Normative sex- and race-specific data regarding the levator muscle are important for providing comparisons to clinical populations, such as individuals with cleft palate, VCFS, and other syndromes.

Methods

Eighty-nine (46 females, 43 males) participants between 18 to 36 years of age were recruited to participate in this study. Because race has been shown to have no influence on the levator muscle measures in adults (Perry et al., 2016), both groups included Caucasian, African American, Asian, Hispanic, and Interracial. All participants were assessed by speech-language pathologist with over 15 years of experience using a 5-point rating scale (0 = typical resonance) at the conversational level to assess resonance. Structural oral abnormalities were evaluated by use of an oral mechanism exam. Participants with a body mass index over 30 were excluded to reduce the risk of claustrophobia and due to the involvement of fat deposits known to increase velar thickness among obese individuals (Horner et al., 1989; Davies et al., 1992). In addition, participants with a history of resonance, swallowing, neurological, hearing, craniofacial, or musculoskeletal disorders, that would alter measures of VP structures and movements, were excluded from the study. This study was reviewed and approved by the local institutional review board.

Magnetic Resonance Imaging and Image Analyses

All participants were scanned without the use of sedation or contrast medium. Participants were scanned in supine position using a Siemens 3 Tesla Trio and a 12-channel Siemens Trio head coil. During the 5-minute scan, subjects were instructed to breathe through their nose with their mouth closed. The velum was in a relaxed and lowered position. Magnetic resonance imaging participants were part of a previously published large-cohort study of VP anatomy (Perry et al., 2016). Participants were imaged across varied MRI sites using a

3D MRI sequences with comparable imaging sequence parameters. Images with excessive motion artifacts were excluded from the study. Definitions and methods for measures used in the present study were based on studies of VP analyses using MRI. A midsagittal slice was first determined based on the presence of the pituitary gland, the fourth ventricle, and genu of the corpus callosum as described. Then, the oblique-coronal slice was overlaid onto the midsagittal slice (Ettema et al., 2002). Data obtained from the oblique coronal image plane represented an entire view of the levator muscle from origin to insertion. The levator muscle bundles were considered from the origin at the base of the skull near the apex of the petrous portion of the temporal bone. This muscle courses anteriorly, medially, and inferiorly to insert into the midsection of the velum. The levator muscle thickness was measured at the lower region of the extravelar segment (Figure 1). This is an easily repeatable measuring location because it is just superior to the insertion of the palatopharyngeus muscle into the body of the velum. As described by Ettema et al. (2002), this location is a more reliable point to measure thickness because regions inferior to this (intravelar regions of the levator) likely include other muscles (eg, palatopharyngeus, palatoglossus, and musculus uvulae). The boundaries for measuring the levator thickness at this region are able to be clearly delineated from the surrounding adipose and connective tissue, which appears bright in the MR images, whereas the muscle is dark. The levator length was the entire length of the muscle bundle from origin to insertion at the velar midsection (Figure 1; Ettema et al., 2002; Perry et al., 2013; Perry et al., 2016). Magnetic resonance images were transferred into the Amira 5.5 Visualization Volume Modeling software (Visage Imaging GmbH).

Nasopharyngoscopy

Flexible nasopharyngoscopy was used to determine the symmetry of VP closure during speech for 39 of the 89 participants. Not all participants completed the nasopharyngoscopy because they were enrolled as part of a separate study, which did not include nasopharyngoscopy. Therefore, results related to the second aim are based solely on 39 of the total 89 participants. The procedures used for nasopharyngoscopy were consistent with that used in previous MRI and nasopharyngoscopy investigation of the VP closure patterns based on anatomic variables (Jordan et al., 2017). The participants were instructed to repeat high and low pressure oral and nasal speech sounds in words, sentences, and connected speech to assess the symmetric or asymmetric function of the VP closure. The function of the VP closure was determined using the Nasopharyngoscopy Rating Form (Kummer, 2013) to assess the videos. The VP closure in each participant was classified using the rating form as symmetric or asymmetric. The asymmetric gap was noted as located in right or left portal area.

Reliability

An Intra-class correlation coefficient was used to determine the intra and inter-rater reliability agreement. The primary rater remeasured 44.9% (40 participants) of MRI data 6 weeks after the first measures. For assessing inter-rater agreement, a secondary rater measured 43.82% (39 participants) randomly selected participants. Kendall τ coefficient was used to measure agreement for nasopharyngoscopy findings obtained from the first and second nasopharyngoscopy evaluations of 100% of nasopharyngoscopy videos (39 participants).

Statistical analysis

The length and thickness of the levator muscle was obtained through Amira 5.5.0 were summarized using descriptive statistics, including means and SD. Kolmogorov-Smirnov test was used to access the normality of data. Matched paired *t* tests or Wilcoxon signed rank tests were conducted as appropriate to compare between the right and left levator length and thickness. Spearman correlation coefficient was calculated to determine the correlation between MRI findings and nasopharyngoscopy observations. Descriptive statistics were used to summarize the measures of the levator muscle bundles in males and females to provide sex-specific normative values. A significance level of $\alpha = 0.05$ was adopted for all statistical tests.

Results

Matched paired *t* tests revealed a nonsignificant difference ($p > .05$) between the mean value of the right and left levator muscle bundles for both length and thickness (Table 1). As shown in Table 1, the mean difference between the right and left length of the levator muscle bundles was 2.28 mm. Although there was no statistically significant difference for group means between the right and left muscle bundles, qualitative differences were evident. More specifically, the range for the difference in the right and left levator muscle length was 0.09 mm to 10.37 mm. The range for the difference in the right and left levator thickness as 0 to 1.53 mm. A rating of 0 indicates that the same value for muscle thickness was recorded for the right and left levator muscle bundles, resulting in 0 difference between the 2 sides. As the Kolmogorov-Smirnov test indicated that the distribution of differences in length and thickness was not quite normal for the female group and total group, we also used Wilcoxon signed rank tests to confirm this observation and had the same conclusions as the matched paired *t* tests. There were no statistically significant differences between the right and left length of the levator muscle ($P = .82$) or between the right and left thickness ($P = .95$) of the levator muscle in total group. In addition, there were no statistically significant differences between the right and left length of the levator muscle ($P > .05$) or between the right and left thickness ($P > .05$) of the levator muscle in each sex group. In addition, matched paired *t* tests revealed a nonsignificant difference ($P > .05$) between the mean value of the right and left levator muscle bundles for both length and thickness in different race groups according to sex groups (Table 1).

A spearman correlation coefficient was used to determine the correlation between MRI findings and nasopharyngoscopy observations. Specifically, the second study purpose was to determine the relation between the differences of the right and left levator muscle length (the right levator muscle length – the left levator muscle length) and the function of VP closure during speech (−1: the right levator muscle is shorter than the left, 0: symmetry, 1: the left levator muscle is shorter than the right). Among 39 participants that were assessed with both MRI and nasopharyngoscopy, asymmetrical VP closure was observed for 10 participants at the first and second nasopharyngoscopic assessment. However, there was a nonsignificant negative ($P = -.106$, $P = .52$) correlation between the function of VP closure and difference of the levator muscle lengths. From 6 participants with the most considerable asymmetry for the length and thickness of the levator muscle, nasopharyngoscopy was completed for 2 participants. No asymmetrical VP closure was observed in participant with 6.73 mm asymmetrical length of the levator muscle bundles. In addition, no asymmetrical VP closure was observed in participant with 1.36 mm asymmetrical thickness of the levator muscle bundles (Figure 2). This suggests that there was no significant association between the asymmetry of the VP closure as observed through nasopharyngoscopy and the degree of symmetry in the levator muscle features as measured through MRI. The intraclass correlation between the primary rater and secondary rater was $r = 0.817$ for MRI measures, indicating good inter-rater reliability. The intraclass correlation between the first and second MRI measurements from the primary rater was $r = 0.878$. The Kendall τ correlation between the first and second assessments of VP closure through nasopharyngoscopy was $\kappa = 0.802$. This indicates good intra-rater reliability for both MRI measurements and nasopharyngoscopy assessments.

Discussion

Results from the current study demonstrate minimal difference between the right and left length and thickness of the levator muscle bundles among individuals with normal anatomy. These findings are in agreement with previous studies among adults with a small sample size (Table 2). According to the current study, the asymmetry between the right and left levator muscle length was 0.13 mm among participants with typical VP anatomy. Variations observed by previous studies compared to the current study may be due to differences in the age of participants, the ex-vivo nature of cadaver dissection compared to the in vivo nature of MRI, effect of obesity, small sample size of less than 10 participants (in vivo studies), and point of measuring the thickness of the levator muscle at the velar midline. The mean differences for the right and left levator muscle length and thickness were minimal in the current study, but the wide range may indicate that typical VP anatomy can be associated with a sizeable (eg, up to 10 mm) difference in the levator muscle length. This raises the question of whether asymmetry in the levator muscle is of clinical significance or not. Likely the answer lies in how the asymmetry contributes to VP closure. To the best of our knowledge, this is the first study to examine measures within a large population of typical participants, and thus in the current study, the typical range of asymmetry for length and thickness of the right and left levator muscle bundles in noncleft anatomy is determined.

The second aim of this study was to examine whether the asymmetry between the features of the levator muscle bundles through MRI results in observable asymmetry in the VP closure through nasopharyngoscopy. The result of this study demonstrated a nonsignificant correlation between the nasopharyngoscopic observations of the VP closure and MRI findings of the levator length in the right and left muscle bundles. More specifically, among 39 participants that were assessed with both MRI and nasopharyngoscopy, asymmetrical VP closure was observed for 10 participants through nasopharyngoscopic assessment. In 6 of 10 participants, no correlation was found between the asymmetrical features of the levator muscle measures obtained from MRI and asymmetric VP closure through nasopharyngoscopy. In addition, no asymmetrical VP closure was observed in the participants with the most considerable asymmetry in the right and left length and thickness of the levator muscle bundles. These findings suggest the asymmetrical features of the levator obtained from MRI does not appear to have an impact on the asymmetric closure of VP sphincter as observed through nasopharyngoscopy. It is likely that other VP muscles contribute collectively to observed asymmetry in VP closure. It is also possible the viewpoint provided by nasopharyngoscopy contributes to perception of asymmetric function of VP closure.

In this study, the right and left length and thickness of the levator muscle bundles in males and females were quantified. Consistent with previous studies (Ettema et al., 2002; Perry et al., 2013), the right and left length and thickness of the levator muscle bundles in males are longer and thicker than females (Table 1). Additionally, the right and left length and thickness of the levator muscle bundles were evaluated in different race and sex groups. Results from the current study demonstrate minimal difference between the right and left length and thickness of the levator muscle bundles among individuals with normal anatomy with different race and sex groups (Table 1). These findings are in agreement with previous study among adults (Perry et al., 2016). In general, the length and thickness of the levator muscle bundles in males are longer and thicker than females for all race groups. Findings from the present study provide normative data, which may be useful for comparison to individuals with atypical VP anatomy.

Collectively, the findings from the present study contribute to the literature by providing a comparative tool for evaluating adults with typical and atypical VP structures. The findings of Park et al. (2015) demonstrated the left muscle thickness of the levator was significantly thicker in VCFS patients. Compared the results of Park et al. (2015) study to the normative data in the present study revealed the levator thickness of patients with VCFS was approximately half of that in typical participants. Although Park et al. (2015) reported 0.5 mm mean thickness asymmetry between the right and left thickness of the levator muscle bundles in patients with VCFS, this degree of asymmetry in thickness was much smaller than that found in the typical population in the current study and may be of no clinical significance. It is important to mention that a range of structural and functional abnormalities such as hypoplasia, upper airway asymmetry, pharyngeal hypotonia, hypodynamic velopharynx, and combined effects of the aforementioned abnormalities contribute to the VP mechanism of patients with VCFS (Chegar et al., 2006). Therefore, these additional structural and functional abnormalities should be considered for comparison of this population with typical population.

The findings of current study are informative; however, they are not without limitations. The small sample size of participants evaluated with both MRI and nasopharyngoscopy may limit conclusions related to the second study aim. Defining the midpoint of the levator muscle was of critical importance, particularly given there is no evident midline separation of the 2 muscle segments through the velar midline. While an intraclass correlation coefficient was determined to be good, small variations in the definition of the muscle midpoint might have altered these findings. Variations of the right and left length and thickness of the levator muscle might be affected by age. In this study, 69 participants were between 18 to 23 years of age and 20 participants between 24 to 36 years of age. The impact of age was therefore not determined in the current study. While it is unlikely that there would be differences among an adult population, data related to pediatric populations should report values by age groups. Future studies are needed to measure the morphology of the levator in the right and left muscle bundles using dynamic MRI. In addition, future studies should determine the correlation between findings of the levator muscle morphology and the VP mechanism during homogenous speech task.

Findings from the present study demonstrate a not statistically significant difference between the length and thickness of the right and left levator muscle bundles among individuals with typical anatomy. The wide range of the levator muscle length may indicate that typical VP anatomy can be associated with a sizeable difference in the levator muscle length. In addition, no direct impact on the closure pattern was observed among individual with sizeable asymmetry of the right and left levator length. This study quantifies the right and left length and thickness of the levator muscle bundles in males and females to provide a comparative tool for evaluating adults with typical and atypical VP structures.

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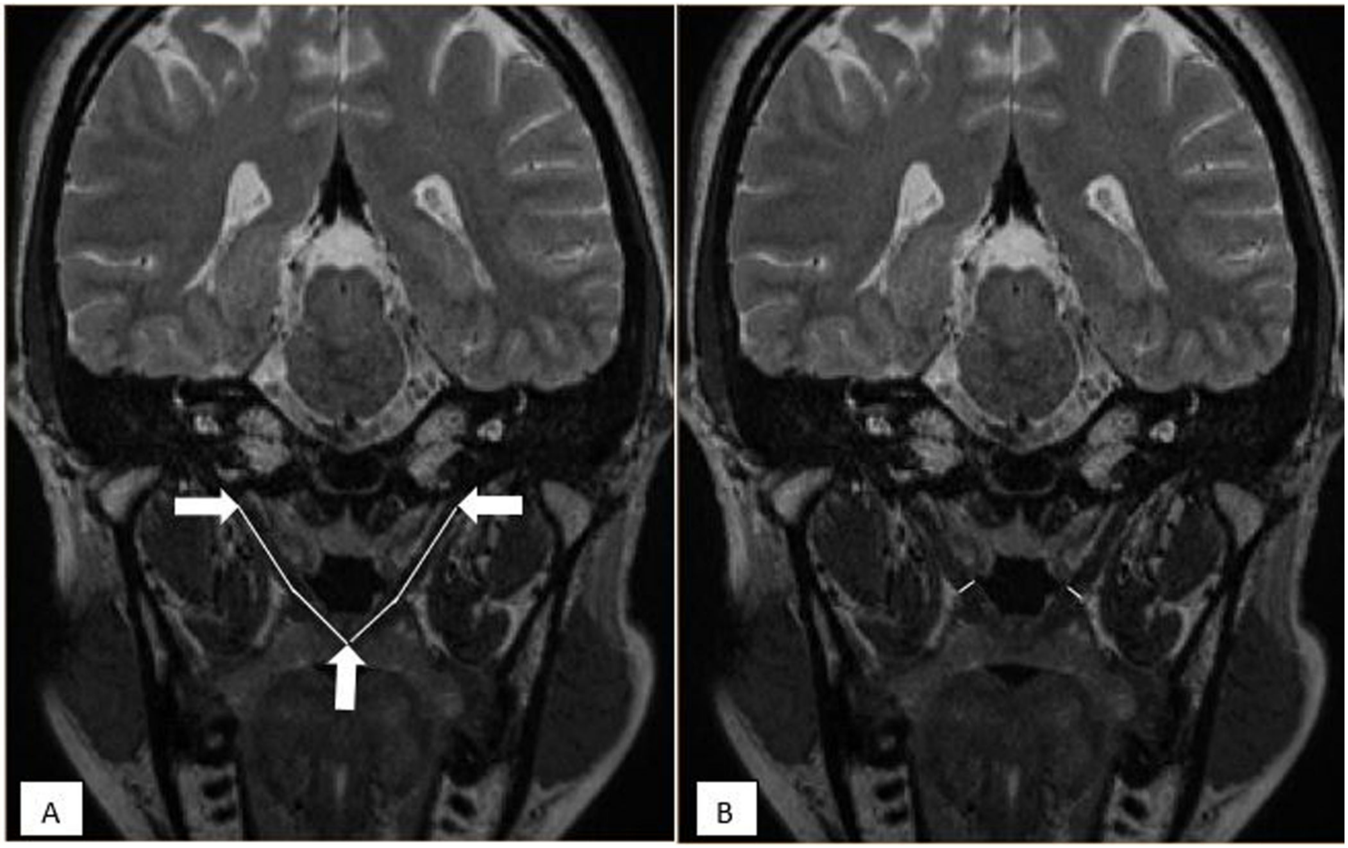

Figure 1.

The levator muscle. A, Magnetic resonance imaging of the oblique coronal plane displaying the levator muscle and the measures obtained on the muscle. The entire length of the muscle bundle represents from origin to insertion at the velar midsection. B, Magnetic resonance imaging of the oblique coronal plane displaying the levator muscle and the measures obtained on the muscle. The white lines depict the thickness for the right and left portion of the levator muscle bundles.

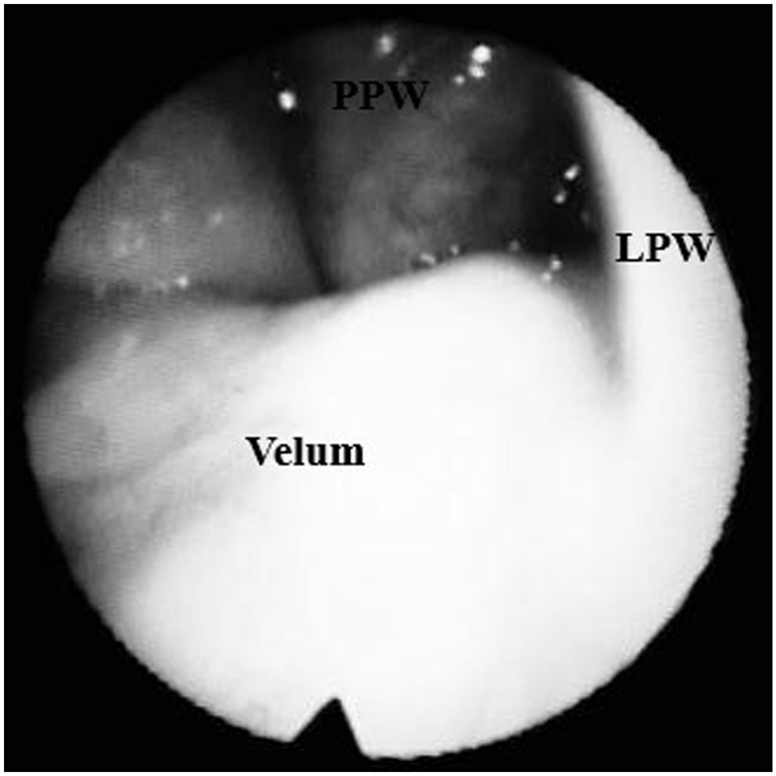

Figure 2.
Asymmetrical VP closure. Nasopharyngoscopy displaying the asymmetrical VP closure. However, magnetic resonance imaging of this participant (Figure 1) displays minimal asymmetry between the right and left length of the levator muscle bundles.
Abbreviation: LPW indicates lateral pharyngeal wall; PPW, posterior pharyngeal wall.

Table 1.

Comparing the Levator Muscle Measures Between the Right and Left Muscle Bundles and by Sex Groups.[a]

Group	N	Right length mean(SD) median	Left length mean(SD) median	Difference of length mean(SD) median	P	Right thickness mean(SD) median	Left thickness mean(SD) median	Difference of thickness mean(SD) median	P
Total	89	43.28 (4.72)	43.15 (6.30)	2.28 (1.97)	0.80[b]	3.60 (0.76)	3.60 (0.76)	0.52 (0.38)	0.98[b]
		42.82	43.57	1.87	0.82[c]	3.53	3.61	0.46	0.95[c]
Male	43	45.76 (4.21)	45.95 (4.50)	2.67 (1.90)	0.72[b]	3.94 (0.72)	3.80 (0.78)	0.59 (0.42)	0.19[b]
		45.62	45.85	2.24	0.77[c]	4.00	3.75	0.53	0.22[c]
		C:46.47(4.88)	C:45.33(4.74)		0.07[b]	C:3.67(0.77)	C:3.65(0.85)		0.9[b]
		45.43	45.79		0.31[b]	3.49	3.62		0.39[b]
		AA:45.22(4.04)	AA:45.94(4.43)		0.49[b]	AA:4.06(0.66)	AA:3.9(0.72)		0.44[b]
		45.58	45.85			4.16	3.87		
		A:46.72(1.13)	A:49.12(3.82)			A:4.3(0.76)	A:4.58(1.24)		
		46.44	51.23			4.04	3.92		
Female	46	40.96 (3.95)	40.54 (6.65)	1.91 (1.98)	0.36[b]	3.28 (0.66)	3.42 (0.70)	0.44 (0.32)	0.09[b]
		40.69	40.76	1.55	0.85[c]	3.13	3.40	0.37	0.17[c]
		C:41.88(5.81)	C:42.08(5.12)		0.68[b]	C: 3.13(0.59)	C:3.3(0.57)		0.21[b]
		41.32	41.49		0.87[b]	3.1	3.25		0.43[b]
		AA:40.93(2.86)	AA:41.02(3.39)		0.29[b]	AA:3.32(0.7)	AA:3.42(0.71)		0.31[b]
		40.45	40.34			3.15	3.4		
		A: 38.84(2.82)	A:40.93(3.48)			A:3.6(0.58)	A:3.58(0.89)		
		39.09	41.26			3.58	4.02		
		I:41.27	I:41.36			I:2.41	I:2.64		

Abbreviations: A, Asian; A.A, African American; C, Caucasian; H, Hispanic; I, interracial.

[a]Means (with SD) and medians are reported in mm.

[b]Matched pairs *t* test.

[c]Wilcoxon signed rank test.

Table 2.

Comparisons of Variables Across Studies That Report the Levator Muscle Length and Thickness.

	Ettema et al. 2002	Tian et al. 2010	Perry et al. 2011	Perry et al. 2013	Azzam et al. 1977	Kuehn and Azzam 1978	Huang et al. 1997	Kotlarek et al. 2020
No. of subjects	10	30 subjects (in 3 groups)	4 (2 subjects without cleft palate)	10	7 human cadavers	25 human cadavers	15 human cadavers	15 subjects (in 3 groups)
Age range	21 to 53 years	4 to 7 years	8 to 9 months	20 to 32 years	40 to 60 years	40 to 70 years	-	4 to 8 years
Gender	5 males and 5 females	10 males and females without cleft palate	Female	Male	4 males and 3 females	10 males and 4 females	9 males and 6 females	-
Race	Caucasian	Asian (chines)	Asian/ White	Caucasian	Not reported	Not reported	Asian	Not reported
Consider the right and left levator muscle bundles	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Consider the effect of sex	Yes	No	Yes	Yes	No	No	No	No
Length of the levator muscle	Females: 44.1mm Males: 46.4 mm	Right: 27.2 mm Left: 27.2 mm	Right: 29.3 mm Left: 30.4 mm	Right: 47.2mm Left: 47.72mm	-	-	-	Avg Extravelar length Noncleft: 25.98 mm VPI: 25.30 mm VPC: 32.85 mm
Thickness of the levator muscle	Females: 3.9 mm Males: 4.6 mm	-	-	-	Right: 8.9 mm Left: 9.1 mm	Right: 8.14 mm Left: 8.34 mm	Right: 7.96 mm Left: 7.94 mm	Midline Noncleft: 3.81mm VPI: 1.32 mm VPC: 3.16 mm Difference at Insertion into velum VPC: 3.16 mm Noncleft: .11 mm VPC: 3.16 mm

	Ettema et al. 2002	**Tian et al. 2010**	**Perry et al. 2011**	**Perry et al. 2013**	**Azzam et al. 1977**	**Kuehn and Azzam 1978**	**Huang et al. 1997**	**Kotlarek et al. 2020**
								VPI: 1.25 mm VPC: 1.31 mm

Abbreviations: VPI, velopharyngeal insufficiency; VPC, velopharyngeal closure.