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Title: Ankyloglossia as a risk factor for maxillary hypoplasia and soft palate elongation: a functional - anatomical study

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Corresponding Author: Dr. Audrey Yoon, DDS MS

Corresponding Author's Institution: UCLA School of Dentistry

First Author: Audrey Yoon, DDS MS

Order of Authors: Audrey Yoon, DDS MS; Soroush Zaghi, MD; Sandy Ha, BA; Clarice Law, DMD, MS; Christian Guilleminault, DM, MD, DBiol; Stanley Y Liu, MD, DDS

Abstract: Purpose: To determine the association of restricted tongue mobility and ankyloglossia on maxillofacial development.

Methods: Prospective cohort study of 302 consecutive subjects from an orthodontic practice. Tongue mobility (as measured with tongue range of motion ratio (TRMR) and Kotlow free tongue measurement) was correlated with measurements of the maxillofacial skeleton obtained from dental casts and cephalometric radiographs.

Results: TRMR and Kotlow measures of restricted tongue mobility are associated with (1) ratio of maxillary inter-canine width to canine arch length, (2) ratio of maxillary inter-molar width to canine arch length, and (3) soft palate length. Restricted tongue mobility was not associated with hyoid bone position or Angle's skeletal classification.

Conclusions: The tongue plays a critical role in maxillofacial development. Restricted tongue mobility is associated with narrow maxillary arch and elongation of the soft palate (Level 2b evidence).

Jan 22th 2017

To the editors,

We are enthused to submit our manuscript for your review:

Ankyloglossia as a risk factor for maxillary hypoplasia and soft palate elongation: a functional – anatomical study.

Ankyloglossia and the importance of tongue mobility has come to the attention of the orthodontic and sleep medicine community, however, there is a lack of investigator-blinded, controlled studies examining the association of lingual frenulum and tongue posture on development of the maxillofacial complex. This is important because the maxillofacial skeleton defines the foundation, dimensions, and patency of the nasal and oropharyngeal airway.

This is a prospective cohort study of 302 patients performed an anatomical- functional investigation of the association between tongue-mobility and maxillofacial development and we found that restricted tongue mobility and ankyloglossia are associated with underdevelopment of the maxillary dentoalveolar complex (Level 2b evidence).

Also this is one of the first to find the association of restricted tongue mobility and increased length of the soft palate and to suggest a potential link between restricted tongue mobility and collapsibility of the upper airway at the velum.

We wish to submit this under Original Articles.

Thank you.

Sincerely yours,

*Title Page

Ankyloglossia as a risk factor for maxillary hypoplasia and soft palate elongation: a functional – anatomical study.

Audrey Yoon DDS, MS[1]; Soroush Zaghi MD[2,3] ,Sandy Ha BA[4]; Clarice S. Law DMD, MS[5] Christian Guilleminault DM, MD, DBiol[6] ,Stanley Y.C. Liu MD, DDS[7].

Affiliations/ Institution

1. Clinical Instructor, Sections of Pediatric Dentistry and Orthodontics, Division of Growth and Development, UCLA School of Dentistry.
2. Staff Physician, Division of Sleep Surgery, Department of Otolaryngology-Head & Neck Surgery, School of Medicine, Stanford University, Stanford, CA 94305.
3. Staff Physician, UCLA Health, Santa Monica, CA 90404.
4. Dental Student, UCLA School of Dentistry, Los Angeles, CA 90095.
5. Associate Clinical Professor, Sections of Pediatric Dentistry and Orthodontics, Division of Growth and Development, UCLA School of Dentistry
6. Professor, Stanford University Sleep Medicine Division, Stanford Outpatient Medical Center, Redwood City, CA 94063.
7. Assistant Professor, Division of Sleep Surgery, Department of Otolaryngology-Head & Neck Surgery, School of Medicine, Stanford University, Stanford, CA 94305

Short Running Title: Restricted tongue mobility and ankyloglossia are associated with maxillary hypoplasia and soft palate elongation

Corresponding Author:

Audrey Jung-Sun Yoon DDS, MS
Section of Pediatric Dentistry
Division of Growth and Development
UCLA School of Dentistry
10833 Le Conte Ave. CHS 20-137
Los Angeles, CA 90095
Phone: (310)825-5619
Fax: (310) 825-8728
Email: jungdds@gmail.com

Keywords: ankyloglossia, frenulum, tongue-tie, oromyofascial dysfunction, maxillofacial development

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Additionally, all authors provided final approval of the version to be published and agreed to be accountable for all aspects of the work including ensuring the accuracy and/or integrity of the work.

Highlights:

1. This is a large prospective cohort study which performed an anatomical- functional investigation of the association between tongue-mobility and maxillofacial development.
2. Our study shows that restricted tongue mobility and ankyloglossia are associated with underdevelopment of the maxillary dentoalveolar complex (Level 2b evidence).
3. Tongue mobility has the strongest association with transverse dimensions of the hard palate, particularly the anterior inter-canine maxillary width.
4. This study is one of the first to find the association of restricted tongue mobility and increased length of the soft palate and to suggest a potential link between restricted tongue mobility and collapsibility of the upper airway at the velum.

Ankyloglossia as a risk factor for maxillary hypoplasia and soft palate elongation: a functional – anatomical study.

Short Running Title: Restricted tongue mobility and ankyloglossia are associated with maxillary hypoplasia and soft palate elongation

Abstract:

Purpose: To determine the association of restricted tongue mobility and ankyloglossia on maxillofacial development.

Methods: Prospective cohort study of 302 consecutive subjects from an orthodontic practice. Tongue mobility (as measured with tongue range of motion ratio (TRMR) and Kotlow free tongue measurement) was correlated with measurements of the maxillofacial skeleton obtained from dental casts and cephalometric radiographs.

Results: TRMR and Kotlow measures of restricted tongue mobility are associated with (1) ratio of maxillary inter-canine width to canine arch length, (2) ratio of maxillary inter-molar width to canine arch length, and (3) soft palate length. Restricted tongue mobility was not associated with hyoid bone position or Angle's skeletal classification.

Conclusions: The tongue plays a critical role in maxillofacial development. Restricted tongue mobility is associated with narrow maxillary arch and elongation of the soft palate (Level 2b evidence).

Keywords: ankyloglossia, frenulum, tongue-tie, oromyofascial dysfunction, maxillofacial development

Introduction:

The tongue is a dynamic oral structure that affects vital functions of taste, speech, mastication, deglutition, oral hygiene, and nasal breathing[1 2]. During development, the tongue maintains a balance of forces between the soft tissue structures and the growing maxillofacial skeleton.[3 4].When tongue mobility is impaired by congenital or developmental conditions (e.g. microglossia, aglossia, tongue hemiatrophy, cleft tongue, bifid tongue[5], oromotor dystonia of cerebral palsy[6], oromotor dyspraxia of William's syndrome[7]), there are severe developmental consequences for the maxillofacial skeleton [8 4]. The most common congenital disorder affecting tongue mobility is lingual frenulum restriction resulting in ankyloglossia (tongue-tie), with an incidence of approximately 4.8% in the newborn population [9].

Tongue mobility is influenced by the length and thickness of the lingual frenulum, which extends from the ventral surface of the tongue to the floor of the mouth [10]. During deglutition, the tongue pushes onto the palate, [11] and the lingual frenulum determines the extent to which the tongue can elevate [3]. The upward pressure of the dorsum of the tongue against the palate contributes the width and shape of the hard palate. A short lingual frenulum will limit upward movement, and the tongue instead thrusts anteriorly. This is associated with an underdeveloped maxilla with reduced palatal width [3]. As a result of maxillary constriction, the tongue becomes positioned inferiorly and posteriorly, which may impair mandibular alveolar growth [12 13]. The palatal bones form the roof of the oral cavity and the floor of the nasal cavity. Maxillary constriction may also be associated with nasal obstruction, mouth breathing, and sleep-disordered breathing[14].

Studies have explored the influence of the tongue and lingual frenulum on dentoalveolar anomalies such as mandibular prognathism, maxillary protrusion, and anterior open bite [3 1 15 13].

However, there remains the need for investigator-blinded, controlled studies examining the association of lingual frenulum and tongue posture on development of the maxillofacial complex. This is important because the maxillofacial skeleton defines the foundation, dimensions, and patency of the nasal and oropharyngeal airway. The objective of this study was to perform an anatomical- functional investigation of the association between tongue-mobility and maxillofacial development in a large cohort.

Methods:

Study Design

This was a prospective cohort study of 302 consecutive subjects evaluated in a private orthodontic practice (AY) in Los Angeles, CA from July 2016 to September 2016. Potential subjects age six and over were invited to participate. Exclusion criteria were as follows: history of prior frenectomy, orthodontia, maxillary expansion, maxillofacial surgery, missing or ectopic eruption of canines or first molars, and functional trismus associated with temporomandibular joint disorder. The study involved three main components: functional measurement of tongue mobility, anatomical measurement of the maxillary and mandibular arches using dental casts, and measurements using standardized diagnostic lateral cephalometric radiographs. The following demographic data were collected: age, gender, height (cm), weight (kg), and BMI (kg/m^2). Patients who participated in the study provided written informed consent for their examination findings, dental casts, radiologic studies, and personal health information to be used for research purposes. The study protocol was approved by the institutional review board (IRB) of University of California, Los Angeles (IRB#16-001286).

Tongue mobility measurements - Assessment of the lingual frenulum and tongue mobility was performed by two measures: (1) Tongue Range of Motion Ratio (TRMR) and (2) Kotlow free tongue measurement. TRMR is calculated as the mouth opening with tongue tip to maxillary incisive papillae (MOTTIP) divided by maximal inter-incisal mouth opening (MIO). To measure MOTTIP, subjects were instructed to "touch the back of the front two teeth with your tongue, and open your mouth." MOTTIP was the inter-incisal measurement (from the incisal edge of the maxillary central incisor to the incisal edge of the mandibular central incisor) obtained at the largest mouth opening at which the tongue would still be able to reach the incisive papillae. For MIO measurement, subjects were instructed to "open your mouth." Subjects were not encouraged to open "as widely as possible." The inter-incisal measurement was obtained on the first mouth opening to avoid jaw protrusion or excessive translation at the temporomandibular joint. Functional TRMR as related to MIO grading scale is rated as follows: Grade 1 = > 80% (complete tongue mobility), Grade 2 = 50-80% (average to mildly restricted tongue mobility), Grade 3 = < 50% (moderately restricted tongue mobility), Grade 4 = < 25% (severely restricted tongue mobility) [16]. Kotlow free-tongue measurement is obtained by measuring the length of the ventral surface of the tongue (while in full extension) from the insertion of the lingual frenulum to the tongue-tip [17]. Normal length is greater than 16 mm. Ankyloglossia is classified as Class I (mild, 12 to 16 mm), Class II (moderate, 8 to 11 mm), Class III (severe, 3 to 7 mm), and Class IV (complete ankyloglossia).

Cephalometric analysis (Figure 1) - Lateral cephalogram performed with subjects in natural head position were obtained prior to initiation of orthodontic treatment. The radiographs were analyzed with Dolphin Image Software 9.0. Landmark identification was carried out manually on digital images using mouse-driven cursor: eight skeletal and one soft tissue landmarks were digitized for each cephalogram. The following two angular and linear parameters were measured: (1) ANB: angle formed between points A, N, and B; (2) SN-Mn: angle formed between the SN line and mandibular plane (mn); (3) H-Mn (mm): perpendicular distance from hyoid (H) to mandibular plane (Mn) which was drawn between gonion (Go) and menton (Me); (4) PNS-P (mm): perpendicular distance between posterior nasal spine (PNS) and tip of soft palate (P), also known as soft palate length. Subjects were classified based on the following ANB angle criteria: Skeletal Class I: 0° to 4°; Skeletal Class II: >4°; Skeletal Class III: <0°. These measurements were performed by a rater blinded to grading of tongue mobility.

Orthodontic Study Models (Figure 2)- Stone dental casts were obtained prior to initiation of orthodontic treatment. The following measurements were obtained using a digital caliper, with the average of three consecutive measurements recorded for each dental arch (maxillary and mandibular): inter-canine width(C), canine arch length(A) , inter-molar width(M), and molar arch length(B). The first molars were used as the reference point for the molar measurements. In addition, for the maxillary cast, the depth of the deepest point of palatal vault (D) and the distance between the gingival margins of the first molars (G) were also recorded. The following parameters, derived from the raw measurements, were then used for analysis: (1) ratio of maxillary and mandibular inter-canine width to canine arch length; (2) ratio of maxillary and mandibular inter-molar width to molar arch length; (3) palatal slope as calculated by the following formula: $\theta = \tan^{-1}(\frac{D}{\frac{1}{2}G})$. These measurements were performed by a rater blinded to grading of tongue mobility.

Data Collection - The study data were collected and managed using REDCap electronic data capture tools hosted at the UCLA Clinical and Translational Science Institute. REDCap (Research Electronic Data Capture) is a secure, web-based application designed to support data capture for research studies, providing: 1) an intuitive interface for validated data entry; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for importing data from external sources [18].

Statistical Analysis - Statistical analyses were performed using JMP Pro 12 (SAS Institute Inc., Cary, NC). Continuous variables are summarized as mean (M) ± standard deviation (SD). Categorical variables are summarized as frequencies and percentages. Univariate analysis with Pearson's Chi Square or independent t-test (continuous variables) was performed to assess for nominal or continuous covariates of tongue measurements including age, gender, height, weight, and BMI. Due to the testing of multiple variables for each outcome, a two-tailed p-value <0.01 was selected as the cut-off to achieve statistical significance;

Results:

Our study included 302 subjects with age ranging from 6-67 years. Demographic factors included age: 18.1 ± 9.4 years (M± SD); gender: 61.9% female; weight: 56.3 ± 17.1 kg; height: 63.0 ± 5.2 inches; BMI: 21.6 ± 5.0 kg/m^2. Ethnicities include asian 39.1% , hispanic 35.8%, white 15%, black 8%. This population includes 47 children (ages 6-11), 160 adolescents (age 12-17), 71 young adults (age 18-35), 23 adults (age 36-64), and 1 senior (age >65). The average

TRMR for the entire cohort was 62.1 ± 13.8 (mean ± SD); the average Kotlow free-tongue length was 17.2 ± 5.9 mm. (Table 1 and 2).

The distribution of TRMR in this cohort was as follows: Grade 1= 6.3% (n=19), Grade 2= 74.8% (n=226), Grade 3= 17.5% (n=53), Grade 4= 1.3% (n=4). The distribution of Kotlow classification was as follows: Normal = 47.0% (n=142), Class 1= 40.7% (n=123), Class 2= 10.9% (n=33), Class 3= 0.99% (n=3), Class 4= 0.33% (n=1). There were no significant differences in age, gender, weight, height, or BMI based on TRMR grade or Kotlow Classification ($p>0.05$).

A number of factors were found to achieve or approach a trend towards statistical significance on univariate analysis for an association between TRMR and dental cast measurements (Table 1). A decreased ratio of maxillary inter-canine width to canine arch length (Ratio Mx C W: AL) was associated with a higher TRMR grade. A decreased ratio of maxillary inter-molar width to molar arch length (Ratio Mx M W:AL) was similarly associated with a higher TRMR grade. Increased palatal slope measurements were associated with the higher TRMR grades. Using cephalometric analysis, the soft palate length (PNS-P line) was showed statistical significance when multivariate analysis was used according to TRMR grade, with greater lengths associated with higher TRMR grades. In the multivariate analysis with Standard Least Squares Regression Model, Ratio Mx C W: AL and PNS-P line were found to be independently associated with TRMR (Beta-estimate +/- Standard error: Ratio MxC W:D = 4.41 +/- 0.88, $p<0.0001$; PNS-P= -0.45 +/-0.15, $p=0.0037$).

Similar factors achieved statistical significance on univariate analysis for an association between Kotlow and dental cast measurements (Table 2). Ratio Mx C W: AL showed a tendency to decrease in association with higher Kotlow ratings, with the exception of the one subject in the

Grade 4 category. Ratio Mx M W: AL also showed statistical significance, but without a clear direction for differences. Using cephalometric analysis, the PNS-P line was found to achieve statistical significance for an association with Kotlow free-tongue measurement, but without a consistent pattern of increase or decrease. In the multivariate analysis with Standard Least Squares Regression Model, Ratio Mx C W: AL and PNS-P line were again found to be independently associated with Kotlow Measurement (Beta-estimate +/- Standard error: Ratio MxC W:AL = 1.36 +/- 0.39, p=0.0005 and PNS-P= -0.19 +/-0.06, p=0.0050). See table 1 and 2 for further details.

TRMR and Kotlow Classification were not significantly associated with either dental classification (with data from dental cast measurement) or skeletal classification (with data from cephalometric analysis) (p>0.05) (Figure 3).

Discussion:

There are four main findings from our functional-anatomical study examining the association between tongue-mobility and maxillofacial development. First, this study shows that reduced TRMR and Kotlow measures of tongue mobility are associated with maxillary arch constriction, characterized by a decreased ratio of maxillary inter-canine width to canine arch length. Restricted tongue mobility was not significantly associated with a smaller ratio of maxillary inter-molar width to molar arch length in the multivariate model. The inter-canine width is more susceptible to restricted tongue mobility than the inter-molar width.

These findings are consistent with prior empirical observations of the association between ankyloglossia and restricted maxillary development. Northcutt et al described the two elements of physiology that are essential to understanding the influence of the lingual frenulum on the dentition: first, muscles determine the shape of bone; and second, food is swallowed by vacuum force in the mouth. To create a vacuum, the tongue is normally elevated to the roof of the mouth, creating a seal and giving the palate its normal shape. […] When upward tongue movement is restricted due to a short lingual frenulum, the tongue must thrust forward to create a seal at the front of the mouth, often causing maxillary protrusion and anterior open bite. […] If the lower lingual frenulum is short, the tongue will not generate enough upward pressure to create a normal palate, and a narrow and underdeveloped palate will result." [3] The data to support these ideas were derived from the author's expert opinion based on informal visual assessment of tongue shape and lingual frenulum in 600 individuals with Class I malocclusions from a single pediatric dental practice, over the course of 18 months (Level 5 evidence).

Defabianis et al illustrated the relationship between restricted tongue mobility and maxillary constriction with a case report treated with lingual frenectomy and followed clinically and radiographically for seven years. This was followed by spontaneous upper arch expansion without orthodontic treatment (Level 4 evidence) [15]. Guilleminault et al more recently presented a case-control series of 150 pediatric patients with lingual frenula that were clinically designated as short (n=63) or normal (n=87), and noted more "high and narrow palatal vault" among subjects in the short frenulum group (Level 3b evidence) [19]. One prior study reported by Garcia Pola et al. had attempted to perform a cross-sectional study to compare restrictions of tongue mobility with dental skeletal development (using a method and scale similar to the TRMR presented here) but they had used loosely defined binary (yes/no) cut offs without consistently applied reference standards for a few dentofacial anomalies (unilateral crossbites, deep overbites, and narrow palates) and did not reach statistical significance to demonstrate associations with any of the outcome variables measured with respect to maxillary or mandibular skeletal development (Level 3b study- negative evidence) [10]. The present study in which we have performed an investigator-blinded cross-sectional study with clinical, radiographic, and dental cast measurements represents the first study in the literature to provide Level 2b evidence in support of an association between restrictions to tongue mobility and underdevelopment of the maxillary dental arch.

The second key finding of this study relates to the statistically significant association between soft palate length (i.e. PNS-P line) and tongue mobility in the multivariate model. Restricted tongue mobility (as measured by either Kotlow free-tongue or TRMR) was found to be an independent predictor of increased soft palate length. This association remained significant when controlling for differences in the measurements of the maxillary skeleton, suggesting that the increased soft palate length was likely not exclusively attributable to increased draping of the soft palate tissue due to diminished tension from inadequate skeletal framework. Prior authors have reported that soft palate length is significantly greater in OSA patients[20], and it is well established that increased soft palate length is a prominent risk factor for upper airway collapsibility [21]. As such, this study is one of the first to suggest a potential link between restricted tongue mobility and collapsibility of the upper airway at the velum.

While further research is indicated to confirm the relationship between tongue-mobility and soft palate length, we postulate that restricted tongue-mobility may contribute to oromyofascial dysfunction (in the form of open mouth breathing and/or altered swallowing pattern) that in turn promotes elongation of the soft palate. It should also be noted that soft palate length has been shown to increase progressively with aging, weight gain, and the presence of snoring, particularly among men [20 22 23].

The third main finding pertains to the lack of association between hyoid bone position (H-MN line) and restricted tongue mobility. A short lingual frenulum is associated with a propensity for low tongue posture, which has been previously associated with an inferiorly positioned hyoid bone in certain groups of patients[24]. The hyoid bone is supported by soft tissue and is not spatially fixed by bony articulations. Thus, the position of the hyoid bone will vary with functional movements such as deglutition, mastication, and breathing. Subjects with atypical patterns of functional movements have been previously found to have alterations in the position of the hyoid bone as compared to normal functioning controls [2]. We did not reproduce the finding that the position of the hyoid bone (H-MN line) to be associated with TRMR or Kotlow measures of tongue mobility.

Finally, we did not find an association between skeletal or dental classifications with restricted tongue mobility. Two prior studies with smaller sample sizes (n=30) [12] and (n=150) [13] found an association between ankyloglossia and skeletal Class III malocclusion. We suspect that ethnic factors may have represented a more significant determinant of facial skeletal development in our cohort. In addition, the patients who participated in this study had all presented for orthodontic treatment and do not accurately reflect the anatomy of population-based controls. Future studies with large sample sizes from the general population of evenly distributed patients with class I, II, III dental and skeletal classifications are needed to evaluate the association between tongue mobility and facial skeletal development.

Conclusion

Our study shows that restricted tongue mobility is associated with underdevelopment of the maxillary dentoalveolar complex (Level 2b evidence). Tongue mobility has the strongest association with transverse dimensions of the hard palate, particularly the anterior inter-canine maxillary width. Restricted tongue mobility was also associated with increased length of the soft palate.

References:

1. Horton CE, Crawford HH, Adamson JE, Ashbell T. Tongue-tie. Cleft Palate J 1969;6:8-23.
2. Carvalho EN, Nouer DF, Garbui IU, Nouer PRA. Relationship of the hyoid bone and posterior surface of the tongue for class II division 1 orthodontic patients. RGO-Rev Gaúcha Odontol 2013;61:61-68.
3. Northcutt ME. The lingual frenum. J Clin Orthod 2009;43:557-565.
4. Srinivasan B, Chitharanjan AB. Skeletal and dental characteristics in subjects with ankyloglossia. Progress in orthodontics 2013;14:1-7.
5. Emmanouil-Nikoloussi E, Kerameos-Foroglou C. Congenital syndromes connected with tongue malformations. Bulletin de l'Association des Anatomistes 1992;76:67-72.
6. Živković Z, Golubović S. Tongue mobility in patients with cerebral palsy. Vojnosanitetski pregled 2012;69:488-491.
7. Hertzberg J, Nakisbendi L, Needleman H, Pober B. Williams syndrome-oral presentation of 45 cases. Pediatric dentistry 1994;16:262-262.
8. Jamilian A, Fattahi F, Kootanayi N. Ankyloglossia and tongue mobility. European Archives of Paediatric Dentistry 2014;15:33-35.
9. Messner AH, Lalakea ML, Aby J, Macmahon J, Bair E. Ankyloglossia: incidence and associated feeding difficulties. Archives of Otolaryngology–Head & Neck Surgery 2000;126:36-39.
10. Pola M, Garcia MG, Martín JMG, Gallas M, Lestón JS. A study of pathology associated with short lingual frenum. Journal of dentistry for children 2002;69:59-62.
11. Olivi G, Signore A, Olivi M, Genovese M. Lingual frenectomy: functional evaluation and new therapeutical approach. Eur J Paediatr Dent 2012;13:101-106.
12. Meenakshi S, Jagannathan N. Assessment of lingual frenulum lengths in skeletal malocclusion. Journal of clinical and diagnostic research: JCDR 2014;8:202.
13. Jang S-J, Cha B-K, Ngan P, Choi D-S, Lee S-K, Jang I. Relationship between the lingual frenulum and craniofacial morphology in adults. American Journal of Orthodontics and Dentofacial Orthopedics 2011;139:e361-e367.
14. Guilleminault C, Akhtar F. Pediatric sleep-disordered breathing: New evidence on its development. Sleep medicine reviews 2015;24:46-56.
15. Defabianis P. Ankyloglossia and its influence on maxillary and mandibular development.(A seven year follow-up case report). The Functional orthodontist 1999;17:25-33.
16. Yoon A, Zaghi S, Weitzman R, Ha S, Law C, Guilleminault C et al. Toward a functional definition of ankyloglossia: validating current grading scales for lingual frenulum length and tongue mobility in 1052 subjects. Sleep Breath 2017.
17. Kotlow LA. Ankyloglossia (tongue-tie): a diagnostic and treatment quandary. Quintessence International 1999;30.
18. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing

translational research informatics support. Journal of biomedical informatics 2009;42:377-381.
19. Guilleminault C, Huseni S, Lo L. A frequent phenotype for paediatric sleep apnoea: short lingual frenulum. ERJ Open Research 2016;2.
20. Shigeta Y, Ogawa T, Tomoko I, Clark GT, Enciso R. Soft palate length and upper airway relationship in OSA and non-OSA subjects. Sleep and Breathing 2010;14:353-358.
21. Sforza E, Bacon W, Weiss T, Thibault A, Petiau C, Krieger J. Upper airway collapsibility and cephalometric variables in patients with obstructive sleep apnea. American journal of respiratory and critical care medicine 2000;161:347-352.
22. Stauffer JL, Buick MK, Bixler EO, Sharkey FE, Abt AB, Manders EK et al. Morphology of the Uvula in Obstructive Sleep Apnea1-3. The American review of respiratory disease 1989;140:724.
23. Malhotra A, Huang Y, Fogel R, Lazic S, Pillar G, Jakab M et al. Aging influences on pharyngeal anatomy and physiology: the predisposition to pharyngeal collapse. The American journal of medicine 2006;119:72. e79.
24. Chauhan A, Autar R, Pradhan KL, Yadav V. Comparison of pharyngeal airway dimension, tongue and hyoid bone position based on ANB angle. National journal of maxillofacial surgery 2015;6:42.

Table 1. Patient Demographics, Dental Cast Measurements, and Cephalometric Analysis by Tongue Range of Motion Ratio Grade. **Indicates statistical significance with p-value <0.01 on univariate analysis. *Indicates that the measurement shows a trend that approaches statistical significance with p-value <0.05. ‡ Indicates statistical significant with p<0.01 on multivariate analysis with a Standard Least Squares Regression Model. Abbreviations: Mx= Maxillary, Mn= Mandibular, C= Canine, M=Molar, W:AL = Ratio of Width to Arch Length, SN-Mn angle=Mandibular plane angle, the angle between SN line, where S=sella and N=nasion and Mn plane, drawn between gonion (Go) and menton (Me), H-Mn (mm)= perpendicular distance from hyoid (H) to mandibular plane (Mn), PNS-P line= perpendicular distance from posterior nasal spine (PNS) and tip of soft palate (P), also known as soft palate length

Table 2. Patient Demographics and Dental Cast Measurements by Kotlow Classification. **Indicates statistical significance with p-value <0.01 on univariate analysis. *Indicates that the measurement shows a trend that approaches statistical significance with p-value <0.05. ‡ Indicates statistical significant with p<0.01 on multivariate analysis with a Standard Least Squares Regression Model. Abbreviations: Mx= Maxillary, Mn= Mandibular, C= Canine, M=Molar, W:AL = Ratio of Width to Arch Length, SN-Mn angle=Mandibular plane angle, the angle between SN line, where S=sella and N=nasion and Mn plane, drawn between gonion (Go) and menton (Me), H-Mn (mm)= perpendicular distance from hyoid (H) to mandibular plane (Mn), PNS-P line= perpendicular distance from posterior nasal spine (PNS) and tip of soft palate (P), also known as soft palate length

Figure 1. Points and measurements for the cephalometric analysis. Nasion (N), point A (A), sella (S), menton (Me), hyoid (H), posterior nasal spine (PNS), tip of soft palate (P), gonion (Go), posterior nasal spine (PNS).

Figure 2. Measurements obtained from maxillary and mandibular dental casts. A-Canine arch length from line connecting central incisors to line connecting canine cusp tips, B-Molar arch length from line connecting central incisors to line connecting 1st molar ML cusps, C-Intercanine width between canine cusp tips, M-Intermolar width between 1st molar ML cusps, D-Depth of deepest point of palatal vault, G-Distance between gingival margins of first molars, θ-Palatal slope

Figure 3. There was no significant association between TRMR and Kotlow’s measurements vs skeletal and dental classification in this series (p>0.05).

Figure1

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Figure2

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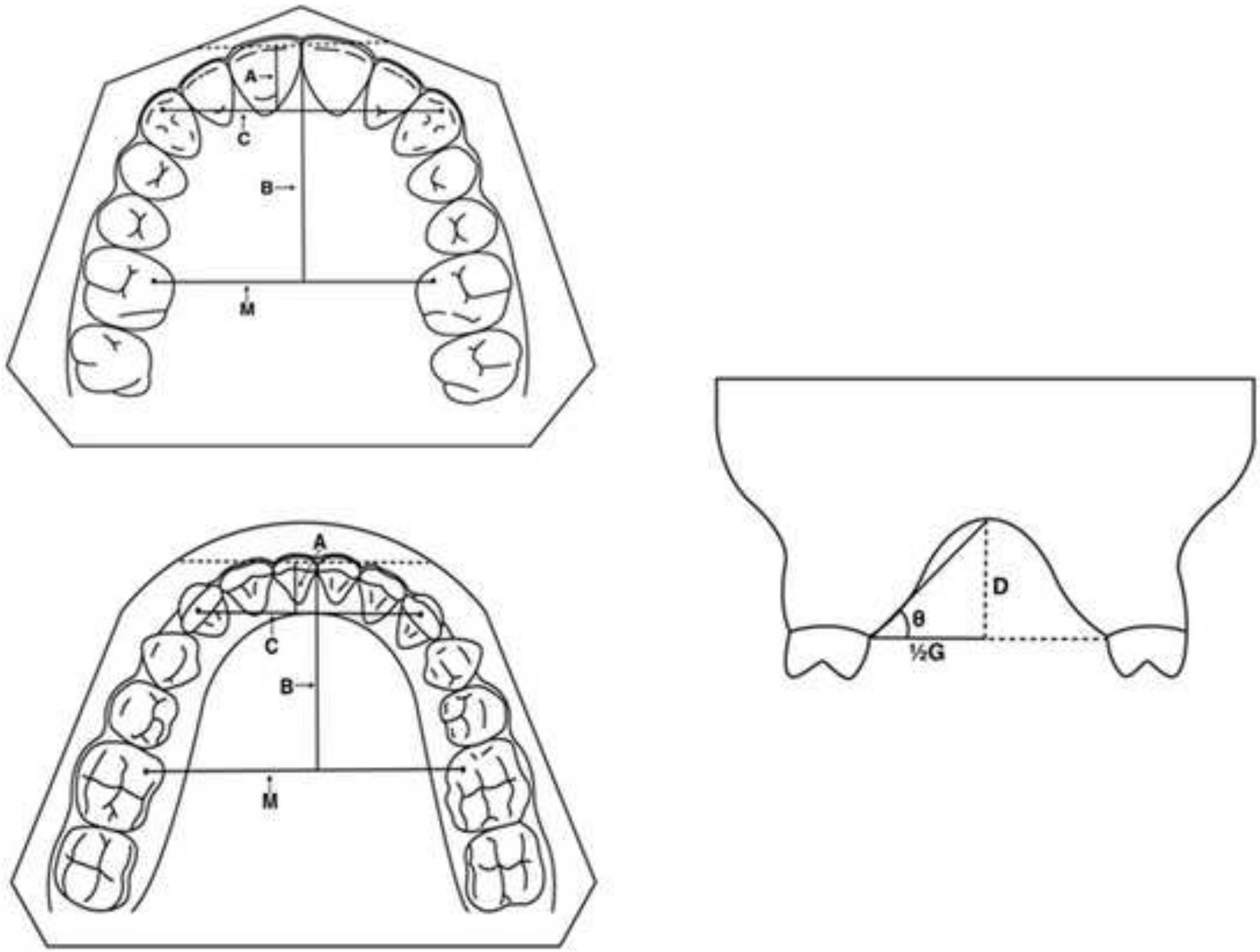

Figure3

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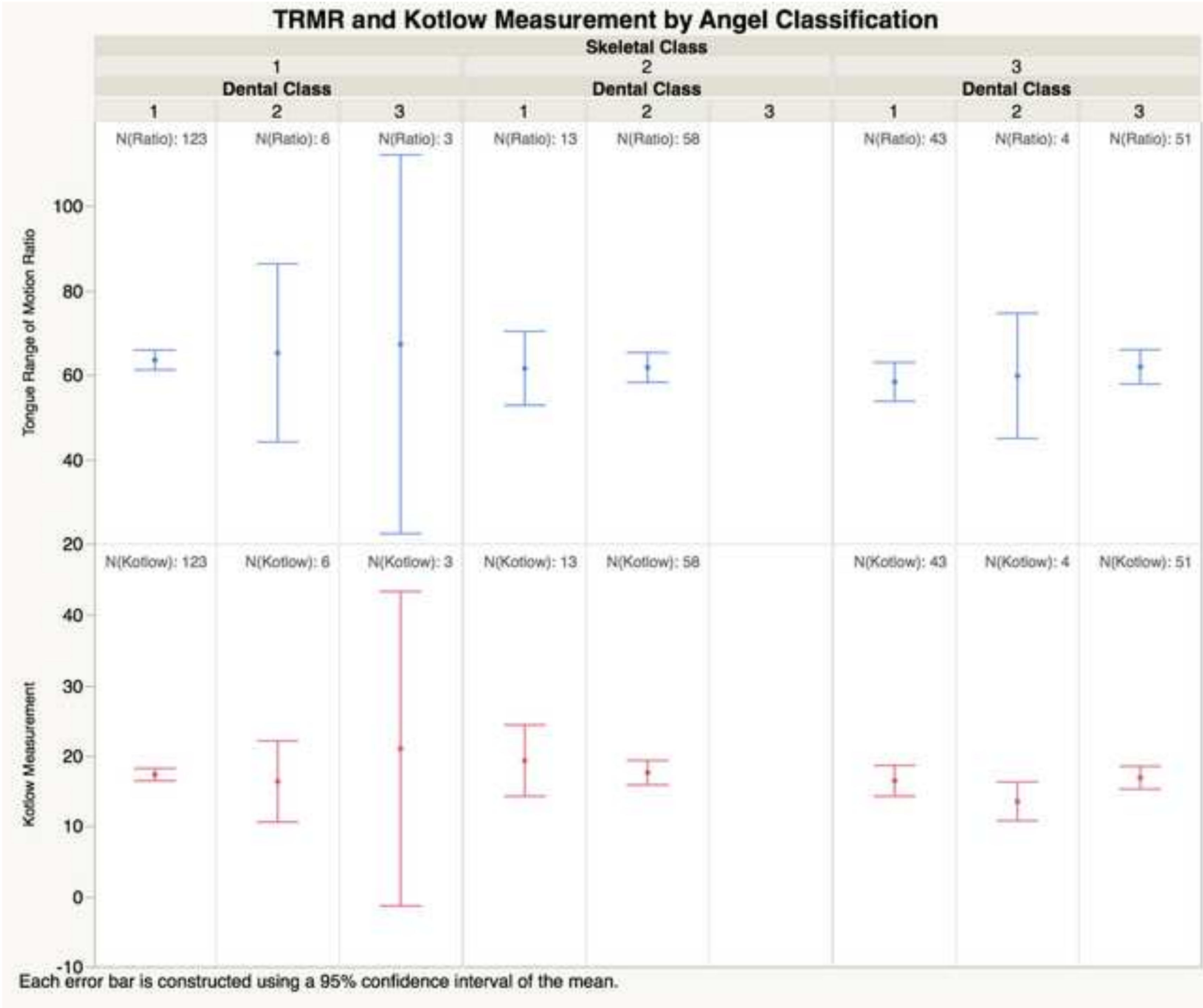

Table 1. Patient Demographics, Dental Cast Measurements, and Cephalometric Analysis by Tongue Range of Motion Ratio Grade. **Indicates statistical significance with p-value <0.01 on univariate analysis. *Indicates that the measurement shows a trend that approaches statistical significance with p-value <0.05. ‡ Indicates statistical significant with p<0.01 on multivariate analysis with a Standard Least Squares Regression Model. Abbreviations: Mx= Maxillary, Mn= Mandibular, C= Canine, M=Molar, W:AL = Ratio of Width to Arch Length, SN-Mn angle=Mandibular plane angle, the angle between SN line, where S=sella and N=nasion and Mn plane, drawn between gonion (Go) and menton (Me), H-Mn (mm)= perpendicular distance from hyoid (H) to mandibular plane (Mn), PNS-P line= perpendicular distance from posterior nasal spine (PNS) and tip of soft palate (P), also known as soft palate length

			TRMR Grade				**P-Value**
		All	**Grade 1**	**Grade 2**	**Grade 3**	**Grade 4**	
			>80%	50-80%	<50%	<25%	
N	Number	302	19	226	53	4	
	% Total	100%	6.3%	74.8%	17.5%	1.3%	
Patient Demographics							
Gender	Male	115 (38.1%)	7 (36.9%)	82 (36.3%)	23 (43.4%)	3 (75.0%)	0.1744
	Female	187 (61.9%)	12 (63.1%)	144 (63.7%)	30 (56.6%)	1 (25.0%)	
Age (years)	Mean	18.1	18.3	18.0	18.9	14.5	0.8103
	Std Dev	9.4	10.6	9.1	10.5	3.9	
Weight (kg)	Mean	56.3	58.9	55.7	57.9	57.5	0.7474
	Std Dev	17.1	24.4	16.0	19.2	14.3	
Height (inches)	Mean	63.0	60.9	63.2	62.8	66.0	0.1857
	Std Dev	5.2	7.9	4.9	5.1	6.3	
BMI (kg/m^2)	Mean	21.6	23.7	21.3	22.2	20.1	0.1404
	Std Dev	5.0	6.6	4.7	5.4	1.7	
TRMR (%)	Mean	62.1	85.5	65.3	42.9	21.4	N/A
	Std Dev	13.8	3.5	8.7	5.0	5.1	
Kotlow (mm)	Mean	17.2	24.9	18.1	11.7	5.3	N/A
	Std Dev	5.9	6.1	5.2	2.3	2.2	
Cast Measurements							
Ratio Mx C W:AL	Mean	3.5	3.6	3.6	3.1	3.0	**0.0015** ‡**
	Std Dev	0.9	0.6	0.9	0.7	0.5	
Ratio Mx M W:AL	Mean	1.2	1.2	1.2	1.1	1.1	**0.0070****
	Std Dev	0.1	0.1	0.1	0.1	0.1	
Ratio Mn C W:AL	Mean	4.7	4.9	4.8	4.4	4.9	0.5446

	Std Dev	1.5	1.2	1.6	1.2	0.8	
Ratio Mn M W:AL	Mean	1.3	1.3	1.2	1.3	1.4	0.2024
	Std Dev	0.2	0.1	0.1	0.2	0.2	
Palatal slope	Mean	35.3	32.4	35.1	36.9	41.4	**0.0118***
	Std Dev	6.5	6.5	6.2	7.5	1.7	
Cephalometric Analysis							
SN-Mn angle	Mean	36.0	36.9	35.7	36.6	40.8	0.2640
	Std Dev	6.1	7.8	5.8	6.4	7.0	
H-Mn line	Mean	12.7	13.4	12.4	13.3	15.7	0.4038
	Std Dev	5.2	7.5	4.8	5.7	5.4	
PNS-P line	Mean	31.6	30.3	31.3	33.5	34.1	**0.0137*** ‡
	Std Dev	5.0	6.2	4.6	5.6	2.8	

Table2

Table 2. Patient Demographics and Dental Cast Measurements by Kotlow Classification. **Indicates statistical significance with p-value <0.01 on univariate analysis. *Indicates that the measurement shows a trend that approaches statistical significance with p-value <0.05. ‡ Indicates statistical significant with p<0.01 on multivariate analysis with a Standard Least Squares Regression Model. Abbreviations: Mx= Maxillary, Mn= Mandibular, C= Canine, M=Molar, W:AL = Ratio of Width to Arch Length, SN-Mn angle=Mandibular plane angle, the angle between SN line, where S=sella and N=nasion and Mn plane, drawn between gonion (Go) and menton (Me), H-Mn (mm)= perpendicular distance from hyoid (H) to mandibular plane (Mn), PNS-P line= perpendicular distance from posterior nasal spine (PNS) and tip of soft palate (P), also known as soft palate length

		Kotlow Classification					
		Normal	**Class 1**	**Class 2**	**Class 3**	**Class 4**	**P-Value**
		> 16 mm	12-16 mm	8-11 mm	3-7 mm	<3mm	
N	Number	142	123	33	3	1	
	% Total	47.0%	40.7%	10.9%	0.99%	0.33%	
Patient Demographics							
Gender	Male	51 (35.9%)	47 (38.2%)	14 (42.4%)	2 (66.7%)	1 (100%)	0.3752
	Female	91 (64.1%)	76 (61.8%)	19 (57.6%)	1 (33.3%)	0 (0%)	
Age (years)	Mean	19.2	17.3	16.9	13.0	19.0	0.3454
	Std Dev	9.4	9.3	9.9	3.0	.	
Weight (kg)	Mean	58.3	54.6	54.0	53.0	70.9	0.3383
	Std Dev	17.1	16.8	18.4	13.6	.	
Height (inches)	Mean	63.3	62.8	62.1	64.3	71.0	0.3851
	Std Dev	4.9	5.2	5.8	6.5	.	
BMI (kg/m^2)	Mean	22.2	21.1	21.1	19.5	21.8	0.4142
	Std Dev	5.0	5.0	4.9	1.5	.	
TRMR (%)	Mean	71.3	57.8	43.7	23.9	13.8	N/A
	Std Dev	8.9	10.2	7.2	1.0	.	
Kotlow (mm)	Mean	22.0	14.0	10.0	6.3	2.0	N/A
	Std Dev	5.0	1.4	1.0	0.6	.	
Cast Measurements							
Ratio Mx C W:AL	Mean	3.7	3.4	3.0	2.8	3.4	**0.0011**** ‡
	Std Dev	0.9	0.8	0.6	0.5	.	
Ratio Mx M W:AL	Mean	1.2	1.2	1.1	1.2	1.1	**0.0027****
	Std Dev	0.1	0.1	0.1	0.1	.	
Ratio Mn C W:AL	Mean	4.7	4.8	4.2	4.8	5.0	0.4236

	Std Dev	1.4	1.6	1.3	1.0	.	
Ratio Mn M W:AL	Mean	1.3	1.2	1.2	1.3	1.5	0.1898
	Std Dev	0.1	0.2	0.2	0.2	.	
Palatal slope	Mean	35.0	35.1	36.5	42.1	39.2	0.2907
	Std Dev	6.1	6.5	8.1	1.1	.	
Cephalometric Analysis							
SN-Mn angle	Mean	36.4	35.5	35.1	43.8	31.5	0.1061
	Std Dev	6.0	6.4	5.1	4.0	.	
H-Mn line	Mean	12.6	12.5	13.5	14.5	19.4	0.5591
	Std Dev	5.1	5.1	5.5	5.8	.	
PNS-P line	Mean	30.9	31.5	34.9	33.3	36.3	**0.0011**‡**
	Std Dev	4.7	5.0	5.3	2.9	.	

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