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# A Retrospective Lateral Cephalometric Growth Study of Sagittal Airway Changes

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LOMA LINDA UNIVERSITY
School of Dentistry
in conjunction with the
Faculty of Graduate Studies

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A Retrospective Lateral Cephalometric Growth Study of Sagittal Airway Changes

by

Grace H. Woo

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A thesis submitted in partial satisfaction of
the requirements for the degree
Master of Science in Orthodontics and Dentofacial Orthopedics

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June 2017

Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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## ABBREVIATIONS

| | |
|---|---|
| SDB | Sleep-Disordered Breathing |
| OSA | Obstructive Sleep Apnea |
| UAR | Upper Airway Resistance |
| ADHD | Attention-Deficit/Hyperactivity Disorder |
| CBCT | Cone Beam Computed Tomography |
| MRI | Magnetic Resonance Imaging |
| AAOF | American Association of Orthodontists Foundation |
| Po | Porion |
| Or | Orbitale |
| ANS | Anterior Nasal Spine |
| A-pt | Point A |
| Maxillary incisor tip | U1 |
| B-pt | Point B |
| Pogonion | Pog |
| 1A-1B | Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical through ANS |
| 2A-2B | Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical through A-pt |
| 3A-3B | Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical through U1 |
| 4A-4B | Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical through B-pt |
| 5A-5B | Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical through Pog |

ABSTRACT OF THE THESIS

A Retrospective Lateral Cephalometric Growth Study of Sagittal Airway Changes
by

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Master of Science in Orthodontics and Dentofacial Orthopedics
Loma Linda University, June 2017
Dr. James Farrage, Chairperson

**Purpose:** This study retrospectively examined the average sagittal dimensions in the pharyngeal airway from skeletal and dental Class I males and females from 7 to 16 years of age utilizing longitudinal data from the American Association of Orthodontists Foundation Craniofacial Growth Legacy Collection. The study evaluated whether average sagittal airway dimensions differed between males and females at each age, and whether the sagittal airway dimension changed with increasing age.

**Materials and Methods:** Sagittal airway dimension based on identifiable anatomical landmarks were digitally traced and measured from the longitudinal lateral cephalograms of 30 females and 32 males from the AAOF Growth Legacy Collection from ages 7 to 16. The distance from the anterior to posterior 2-D limit of the airway along a line perpendicular to Frankfort Horizontal and passing through the anterior nasal spine (ANS) (Measurement 1A-1B), through A-point (Measurement 2A-2B), through upper incisor tip (Measurement 3A-3B), through B-point (Measurement 4A-4B), and throughPogonion (Pog) (Measurement 5A-5B) was measured.

**Results:** ANCOVA showed that males had a statistically significant greater 3A-3B length than females at age 13 ($P$ = 0.02), 15 ($P$ = 0.01), and 16 ($P$ = 0.04). In males, there was a statistically significant increase in 2A-2B length (*P* = 0.04) and 5A-5B length (*P* = 0.03) between ages 7 and 16. No other comparisons were statistically significant.

**Conclusions:** No statistically significant difference was found in sagittal airway dimension between males and females. No statistically significant difference was found in change in sagittal airway dimension with increasing age. We were unable to establish normative values.

# CHAPTER ONE

## REVIEW OF THE LITERATURE

The upper airway consists of the pharynx and nasal cavities. The pharynx is a muscular tube acting as a passageway for food and air. It is bounded anteriorly by the oral cavity and the nasal cavity; posteriorly by the pharyngeal constrictors; superiorly by the soft palate and parts of the cranial base; and inferiorly by the posterior tongue.[1] The pharynx can be divided into three parts: the nasopharynx, oropharynx, and laryngopharynx, which join the nasal cavity, oral cavity, and larynx, respectively, to the pharynx.[1]

It is believed that the pharyngeal morphological changes are related to dentofacial growth, development, and form. [2,3] According to Ceylan et al., Balters' philosophy suggests that a posteriorly-positioned tongue obstructing the upper region of the airway is the cause of Class II malocclusions, leading to mouth-breathing and impaired swallowing, while a more anteriorly-positioned tongue and over-development of the upper region of the airway cause Class III malocclusions.[3] Despite some uncertainties regarding the exact relationship between mouth breathing, pharyngeal airway space, and the development of malocclusions,[4,5] a number of studies suggest that a hyperdivergent facial growth pattern is associated with a pharyngeal airway impairment and mouth breathing.[6-9]

Upper airway dimension is also clinically relevant due to its relationship with sleep-disordered breathing (SDB).[10] Among the clinical signs of SDB are snoring, upper airway resistance (UAR), and obstructive sleep apnea (OSA). Many of these clinical signs are often the result of anatomic constrictions, neuromuscular problems, craniofacial morphology, or a combination of these factors.[11] Untreated OSA in adults was associated with cardiovascular disease and hypertension.[12] Studies suggest that untreated SDB in children is associated with attention-deficit/hyperactivity disorder (ADHD), snoring, daytime sleepiness, and a relatively lower academic performance.[2,13,14]

A common cause of anatomic constrictions of the airway is adenotonsillar hypertrophy, especially in children and adolescents with SDB.[15] Since the majority of orthodontic patients are children and adolescents, orthodontists are in a primary position to screen patients for adenotonsillar hypertrophy and refer to an otolaryngologist as needed. Comprehensive orthodontic care includes growth modification to improve not only esthetics but also function.[16]

Additional research has suggested several treatment modalities such as extractions,[17,18] headgear,[19,20] and Class 2 functional appliances[21] can also affect upper airway dimension. However, little evidence currently exists suggesting a definitive relationship between various treatments and airway dimension.[22]

With the advent of CBCT imaging, the question of the usefulness and accuracy of 2-D cephalometrics in comparison to 3-D CBCT imaging has been raised. CBCT allows the clinician to visualize and analyze structures in different dimensions, while the conventional lateral cephalogram allows measurements limited to the sagittal view.

While several methods including nasal endoscopy, conventional 2-dimensional (2-D) lateral cephalograms, rhinomanometry, 3-dimensional (3-D) cone beam computed tomography (CBCT), and magnetic resonance imaging (MRI), can be used to identify adenotonsillar hypertrophy, the conventional 2-dimensional lateral cephalogram is believed by some authors to be the most cost-effective, reproducible, and clear method to determine adenotonsillar size.[23-25] Lateral cephalograms have been found to be a valid and reliable initial screening tool for constricted airways. Conventional 2-D lateral cephalograms have been proven to be a reliable tool for determining decreased pharyngeal dimensions in OSA patients[26] and in the oropharynx.[27,28] Vizzotto et al. [29] found that measurements made in the nasopharynx and oropharynx in a 2-D cephalogram correlated positively with the 2-D lateral cephalogram constructed from the CBCT. Thus, while measurements made on a 2-D conventional lateral cephalogram of upper airway assessment are limited given that it represents a 2-D image of a 3-D structure, the conventional lateral cephalogram is a reliable initial tool that can orthodontists can routinely use to assess sagittal airway dimension,[30] after which the orthodontist can determine whether the patient requires more rigorous follow-up.[31]

# CHAPTER TWO

# A RETROSPECTIVE LATERAL CEPHALOMETRIC GROWTH STUDY OF SAGITTAL AIRWAY CHANGES


## Abstract

**Purpose:** This study retrospectively examined the average sagittal dimensions in the pharyngeal airway from skeletal and dental Class I males and females from 7 to 16 years of age utilizing longitudinal data from the American Association of Orthodontists Foundation Craniofacial Growth Legacy Collection. The study evaluated whether average sagittal airway dimensions differed between males and females at each age, and whether the sagittal airway dimension changed with increasing age.

**Materials and Methods:** Sagittal airway dimension based on identifiable anatomical landmarks were digitally traced and measured from the longitudinal lateral cephalograms of 30 females and 32 males from the AAOF Growth Legacy Collection from ages 7 to 16. The distance from the anterior to posterior 2-D limit of the airway along a line perpendicular to Frankfort Horizontal and passing through the anterior nasal spine (ANS) (Plane 1A-1B), through A-point (Plane 2A-2B), through upper incisor tip (Plane 3A-3B), through B-point (Plane 4A-4B), and through Pogonion (Pog) (Plane 5A-5B) was measured.

**Results:** ANCOVA showed that males had a statistically significant greater 3A-3B length than females at age 13 ($P$ = 0.02), 15 ($P$ = 0.01), and 16 ($P$ = 0.04). In males, there was a statistically significant increase in 2A-2B length ($P$ = 0.04) and 5A-5B length ($P$ = 0.03) between ages 7 and 16.  No other comparisons were statistically significant.

**Conclusions:** No statistically significant difference was found in sagittal airway dimension between males and females. No statistically significant difference was found in change in sagittal airway dimension with increasing age. We were unable to establish normative values.

## Introduction

Determining average values for sagittal upper airway dimension in adolescents is critical for recognizing deviations from normative values, which may aid in the early diagnoses of constricted airways. Early diagnosis and treatment of constricted airways may help promote normal facial development.[1] In addition, as patients age, they may become more predisposed to constricted airways due to weight gain and other factors associated with aging; thus, early diagnosis and treatment in pre-adolescence or adolescence may help minimize airway constriction in adulthood.[2,3]

Several non-longitudinal studies have determined average sagittal upper airway dimensions for adolescents in different populations, including Turkey, Switzerland, and Brazil.[3,4] [5] However, this study was longitudinal and thus controlled for confounding variables caused by inter-subject variability.

In addition, literature on average sagittal dimensions for the pharyngeal airway is lacking.[3] There is a scarcity of studies regarding the development of the sagittal airway dimension in children and sagittal airway dimension in relation to age and gender.[3]

The American Association of Orthodontists Foundation (AAOF) Craniofacial Growth Legacy Collection provides a database for lateral cephalograms from several locations around the United States of America.  The Case Western Bolton-Brush, University of Oklahoma Denver, Michigan, and Oregon Growth Study populations were utilized for this study. Past cross-sectional studies have analyzed the sagittal airway dimensions of different subjects in different age groups. However, the populations in each AAOF Growth Study consisted of serial cephalometric radiographs taken for each patient, with the majority having taken radiographs either annually or bi-annually, during active growth periods between the 1930s to 1970s.[6]

This population provided standardized data, allowing the measurement of the sagittal upper airway dimensions every year from 7-16 years-old. The aims of this retrospective longitudinal study were 1) to provide average values for sagittal upper airway dimensions and 2) to determine the presence of any growth trends in sagittal upper airway dimensions between 7 and 16 years-old. No studies have been published on sagittal upper airway dimensions for subjects with lateral cephalograms taken yearly or bi-annually during growth between 7-16 years of age.

Null hypotheses: 1) No statistically significant difference exists in sagittal upper airway dimension (nasopharynx and oropharynx) between males and females in each age group between 7 to 16 years old, and 2) No statistically significant change exists in sagittal upper airway dimension (nasopharynx and oropharynx) with increasing age.

## Material and Methods

### *Patient Selection*

The online AAOF Craniofacial Growth Legacy Collection for the Bolton-Brush, Denver, Michigan, and Oregon Growth Study populations were queried for male and female dental Angle Class I patients that had readable lateral cephalograms. Exclusion criteria were:

- Missing more than one cephalogram in the series between 7 and 16-years-old inclusive
- Missing one cephalogram at either 7 or 16-years-old
- Not being Angle Class I dental relationship
- Fixed appliances at any point along the longitudinal series
- Not being skeletal Class 1 relationship (ANB less than 1° or greater than 5°) at age 7
- First molars not occluding either due to delay of eruption or open bite at age 7 or 16
- Cephalogram with poor resolution after digitally adjusting the image at age 7 or 16
- Cephalogram with landmarks cut off at age 7 or 16

The study included the subject if he or she had at most one cephalogram that had poor resolution, an indistinguishable landmark, was not in occlusion, or was missing a cephalogram that was not taken at age 7 or 16. 32 male and 30 female patients were included in this study, resulting in exactly 620 cephalograms as some subjects had at most one cephalogram missing in the series. Table 1 shows the number of males and females that were included for the study from each location.

All subjects were orthodontically untreated Caucasians, and cephalograms were taken no more than 6 months before or after their birthdays.[7,8] When more than one cephalogram was taken within 6 months of the patient's birthday, the cephalogram taken closest to the birthday was used.

Table 1. Demographics of Subjects Derived from the Various Longitudinal Growth Studies

| | **M** | **F** | **Total** |
|---|---|---|---|
| **Bolton-Brush** | 3 | 6 | 9 |
| **Denver** | 9 | 6 | 15 |
| **Michigan** | 13 | 4 | 17 |
| **Oregon** | 7 | 14 | 21 |
| **Total** | **32** | **30** | **62** |

### *Image Acquisition and Data Collection*

Quick Ceph Studio® (Version 3.9.1; Quick Ceph Systems, Inc, San Diego, Calif) was used to digitally trace all landmarks and make measurements. Before tracing, each image was scaled in Quick Ceph Studio® based on the instructions given by the AAOF. The brightness, contrast, and gamma of each image were digitally manipulated to increase the clarity of a given landmark.

A vertical line perpendicular to Frankfort Horizontal (line from mechanical Porion to Orbitale) through Orbitale was drawn, called Orbitale Vertical. The mid-point of the ear-rod was established as the mechanical Porion in order to eliminate a potential error caused by different-sized ear-rods based on location and by an inability to distinguish between the right vs. left Porion.

The nasopharynx is bounded superiorly by the mucosa overlying the posterior part of the body of the sphenoid and the basilar part of the occipital bone posteriorly to the pharyngeal tubercle.[9] The floor of the nasopharynx consists of the nasal upper surface of the soft palate.[9] The oropharynx is bounded superiorly by soft palate and inferiorly by the upper border of the epiglottis.[9]

Five horizontal lines perpendicular to Orbitale Vertical were digitally traced through each of the following five landmarks: ANS, A-pt, U1, B-pt, and Pog (Table 2). The cephalometric analysis of the Arnett-Gunson FAB surgery was applied, with the addition of ANS. The sagittal dimension of the airway was measured along the five horizontal lines from the most anterior to the most posterior limit of the airway (Table 3). In addition, Total Face Height (TFH), Facial Axis (FA), and Mandibular Plane Angle (MPA) were measured for each cephalogram.

Table 2. Cephalometric Landmarks

| Landmarks for Orientation | Abbreviation | Definition |
|---|---|---|
| Mechanical Porion | Po | The center of the ear-rod |
| Orbitale | Or | The most inferior point on the margin of the orbit |
| **Landmarks for Measurement** | | |
| Anterior Nasal Spine | ANS | The anterior limit of the anterior nasal spine |
| Point A | A-pt | The most concave point of the anterior maxilla |
| Maxillary incisor tip | U1 | The incisal tip of the most prominent maxillary incisor |
| Point B | B-pt | The most concave point on the mandibular symphysis |
| Pogonion | Pog | The most anterior point of the mandibular symphysis |

Table 3. Sagittal Airway Dimension Measurements Along Five Planes

| Plane | Definition |
|---|---|
| 1A-1B | Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical and through ANS |
| 2A-2B | Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical and through A-pt |
| 3A-3B | Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical and through U1 |
| 4A-4B | Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical and through B-pt |
| 5A-5B | Distance from most anterior to posterior limit of airway, along line perpendicular to Orbitale Vertical and through Pog |

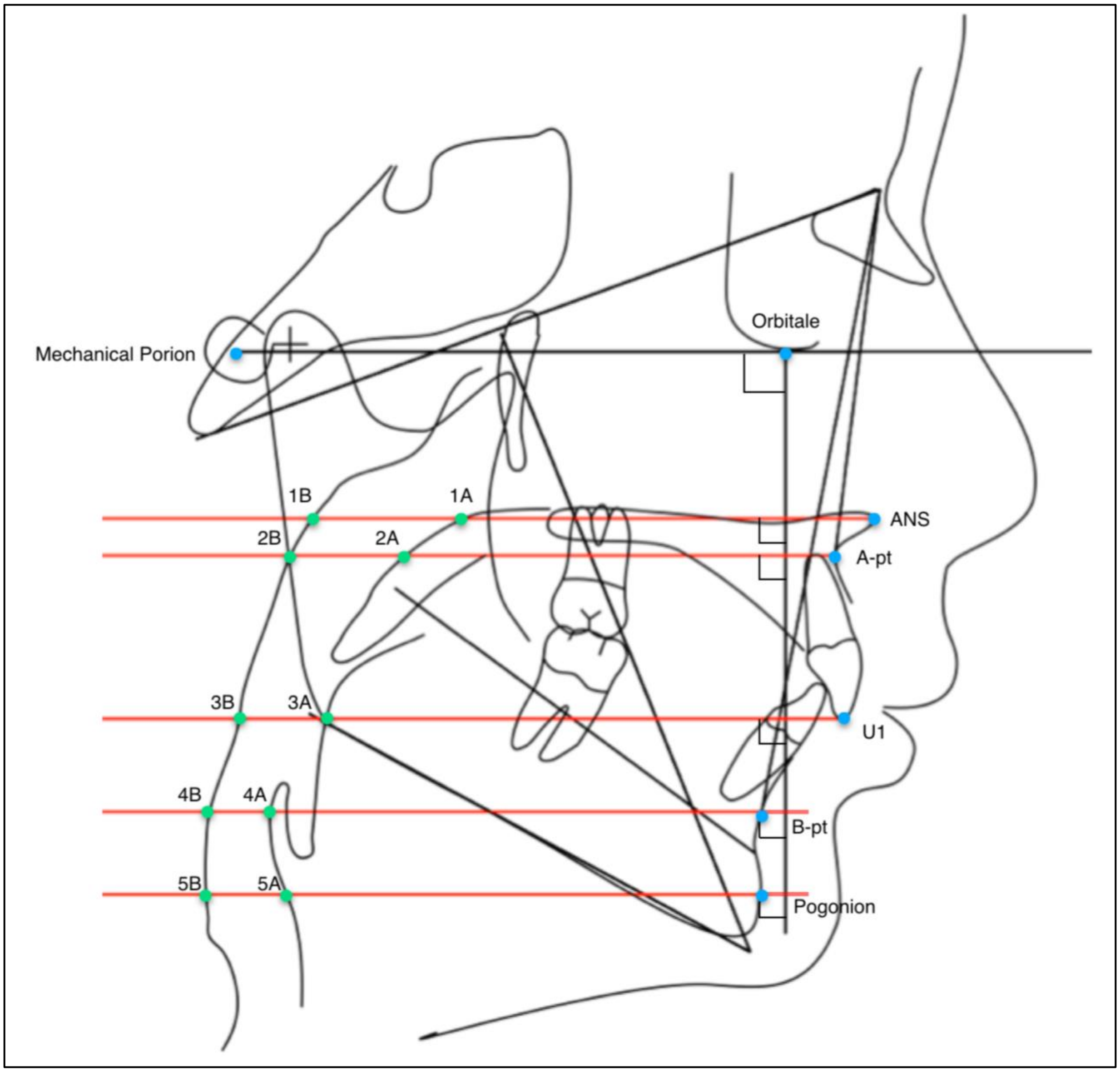


Figure 1. Landmarks and the 5 Sagittal Airway Dimension Measurements Along 5 Planes

Figure 1 illustrates the landmarks and sagittal airway dimensions measured. Appendix A illustrates the digital tracing on a cephalogram using Quick Ceph Studio®. Appendix B shows the numerical values of all measurements.

Deciduous incisors were traced when erupted permanent incisors were absent on a cephalogram. In instances when a patient had no erupted incisors, the tip of the developing incisor was traced. When incisors were not aligned, the most anterior incisor was traced. All distances and angles were measured to the nearest tenth of a millimeter and degree.

In summary, the values recorded were: imaging location, patient ID, gender, age, TFH, FA, MPA, ANB, 1A-1B, 2A-2B, 3A-3B, 4A-4B, 5A-5B.

### ***Statistical Analysis***

SPSS™ 23.0 (SPSS Inc., Chicago, IL, USA) and Microsoft® Excel were used for statistical analyses.

The Kolmogorov-Smirnov test was used to determine normality of the data. Analysis of co-variance (ANCOVA) was run to ascertain any independent effect from multiple co-variates (age, gender, location of study) on the measurements. In all tests, a P-value less than 0.05 was set as statistical significance. The estimated marginal mean for each of the five airway measurements, was calculated.

Intra-observer reliability of measurements was performed using 17 randomly selected patients. Repeat measurements were conducted with a 2-week washout period. The Intraclass Correlation Coefficient (ICC) was used to determine whether there was intra-observer error associated with the digital tracings and measurements.

The average ICC was 94.9% with standard deviation 2.3%, and the median was 95.4% (Table 3). The lowest ICC was 4A-4B at age 10 (87.9%) and the greatest was 3A-

3B at age 12 (99.1%). The ICC demonstrated excellent agreement in all airway measurements (Table 4).

Table 4. Intraclass Correlation Coefficient

| | **Intraclass Correlation Coefficient** |
|---|---|
| **Average** | 0.949 |
| **Median** | 0.954 |
| **Min** | 0.879 |
| **Max** | 0.991 |
| **Standard Deviation** | 0.023 |

## Results

A one-way ANOVA and post-hoc Tamhane test showed that location had statistically significant independent effects on the measurements (Table 5). Thus, location was controlled for in all the analyses.

The results of the ANCOVA demonstrating a mean difference in sagittal airway dimension between males and females within each age category for each of the five planes is shown in Table 6. Males had a statistically significant greater 3A-3B length than females at age 13 ($P = 0.02$), 15 ($P = 0.01$), and 16 ($P = 0.04$).

The ANCOVA showing the difference in sagittal airway dimension between each consecutive age category is shown in Table 7. In males, there was a statistically significant increase in 2A-2B ($P = 0.04$) and 5A-5B ($P = 0.03$) between ages 7 and 16.

Table 5. Post-Hoc Tamhane Test showing Differences in Measurements based on Location.
1=Bolton-Brush, 2= Denver, 3=Michigan, 4=Oregon

| Plane | Group I | Group J | Mean difference (I-J) | Std. Error | P-value | |
|---|---|---|---|---|---|---|
| **1A-1B** | 1 | 2 | -1.8 | 0.4 | 0.00 | * |
| | | 3 | -2.4 | 0.4 | 0.00 | * |
| | | 4 | -1.3 | 0.4 | 0.01 | * |
| | 2 | 3 | -0.7 | 0.4 | 0.51 | |
| | | 4 | 0.4 | 0.4 | 0.80 | |
| | 3 | 4 | 1.1 | 0.4 | 0.05 | |
| **2A-2B** | 1 | 2 | -1.6 | 0.4 | 0.00 | * |
| | | 3 | -1.1 | 0.4 | 0.05 | |
| | | 4 | -0.9 | 0.3 | 0.08 | |
| | 2 | 3 | 0.6 | 0.4 | 0.59 | |
| | | 4 | 0.8 | 0.3 | 0.11 | |
| | 3 | 4 | 0.2 | 0.4 | 1.00 | |
| **3A-3B** | 1 | 2 | -2.5 | 0.4 | 0.00 | * |
| | | 3 | -2.6 | 0.4 | 0.00 | * |
| | | 4 | -2.2 | 0.4 | 0.00 | * |
| | 2 | 3 | 0.9 | 0.5 | 0.27 | |
| | | 4 | 1.3 | 0.4 | 0.02 | * |
| | 3 | 4 | 0.4 | 0.4 | 0.93 | |
| **4A-4B** | 1 | 2 | -2.5 | 0.3 | 0.00 | * |
| | | 3 | -1.9 | 0.3 | 0.00 | * |
| | | 4 | -2.1 | 0.3 | 0.00 | * |
| | 2 | 3 | 0.6 | 0.3 | 0.47 | |
| | | 4 | 0.4 | 0.3 | 0.76 | |
| | 3 | 4 | -0.2 | 0.3 | 0.99 | |
| **5A-5B** | 1 | 2 | -2.4 | 0.4 | 0.00 | * |
| | | 3 | -2.8 | 0.4 | 0.00 | * |
| | | 4 | -2.7 | 0.4 | 0.00 | * |
| | 2 | 3 | -0.9 | 0.3 | 0.06 | |
| | | 4 | -0.3 | 0.3 | 0.92 | |
| | 3 | 4 | 0.6 | 0.3 | 0.37 | |
| **ANB** | 1 | 2 | 1.2 | 0.2 | 0.00 | * |
| | | 3 | 1.1 | 0.2 | 0.00 | * |
| | | 4 | 0.1 | 0.2 | 0.98 | |
| | 2 | 3 | -0.2 | 0.1 | 0.77 | |
| | | 4 | -1.1 | 0.1 | 0.00 | * |
| | 3 | 4 | -0.9 | 0.2 | 0.00 | * |
| **Facial Axis** | 1 | 2 | 1.5 | 0.4 | 0.00 | * |
| | | 3 | 1.7 | 0.6 | 0.01 | * |
| | | 4 | 3.7 | 0.5 | 0.00 | * |
| | 2 | 3 | 0.2 | 0.5 | 1.00 | |
| | | 4 | 2.2 | 0.4 | 0.00 | * |
| | 3 | 4 | 1.9 | 0.5 | 0.00 | * |
| **MPA (mandibular plane angle)** | 1 | 2 | 1.4 | 0.9 | 0.56 | |
| | | 3 | -3.4 | 0.8 | 0.00 | * |
| | | 4 | -1.3 | 0.8 | 0.57 | |
| | 2 | 3 | -3.2 | 1.0 | 0.00 | * |
| | | 4 | -2.7 | 1.1 | 0.08 | |
| | 3 | 4 | 3.1 | 0.9 | 0.01 | * |
| **TFH (total face height)** | 1 | 2 | 2.7 | 0.8 | 0.01 | * |
| | | 3 | 2.3 | 1.1 | 0.19 | |
| | | 4 | 0.6 | 0.7 | 0.93 | |
| | 2 | 3 | -0.4 | 1.2 | 1.00 | |
| | | 4 | -2.1 | 0.9 | 0.12 | |
| | 3 | 4 | -1.7 | 1.1 | 0.62 | |

*P<0.05.

Table 6. ANCVOA Showing the Difference Between Males and Females

| Plane | | 1A-1B | | 2A-2B | | 3A-3B | | 4A-4B | | 5A-5B | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Age** | **Gender** | **Mean** | **P-value** | **Mean** | **P-value** | **Mean** | **P-value** | **Mean** | **P-value** | **Mean** | **P-value** |
| **7** | **F** | 13.9 | 0.12 | 12.1 | 0.09 | 11.3 | 0.11 | 7.7 | 0.95 | 11.3 | 0.96 |
| | **M** | 12.5 | | 10.8 | | 12.9 | | 7.8 | | 11.2 | |
| **8** | **F** | 13.2 | 0.99 | 11.9 | 0.73 | 11.3 | 0.20 | 7.6 | 0.76 | 11.3 | 0.38 |
| | **M** | 13.2 | | 11.6 | | 12.8 | | 7.8 | | 12.1 | |
| **9** | **F** | 14.7 | 0.12 | 12.7 | 0.38 | 11.2 | 0.43 | 8.3 | 0.95 | 11.7 | 0.45 |
| | **M** | 13.0 | | 11.8 | | 12.1 | | 8.4 | | 12.3 | |
| **10** | **F** | 15.4 | 0.14 | 13.0 | 0.52 | 12.1 | 0.97 | 7.4 | 0.35 | 11.8 | 0.54 |
| | **M** | 13.8 | | 12.4 | | 12.1 | | 8.2 | | 12.2 | |
| **11** | **F** | 15.1 | 0.66 | 12.5 | 0.67 | 11.6 | 0.46 | 7.8 | 0.81 | 12.4 | 0.73 |
| | **M** | 14.6 | | 12.9 | | 12.4 | | 8.0 | | 12.6 | |
| **12** | **F** | 14.6 | 0.91 | 12.4 | 0.41 | 11.0 | 0.37 | 7.2 | 0.44 | 12.2 | 0.87 |
| | **M** | 14.8 | | 13.2 | | 12.2 | | 7.8 | | 12.3 | |
| **13** | **F** | 15.8 | 0.52 | 13.1 | 0.62 | 11.2 | 0.02* | 7.8 | 0.26 | 12.7 | 0.82 |
| | **M** | 15.1 | | 13.6 | | 13.8 | | 8.7 | | 12.9 | |
| **14** | **F** | 15.6 | 0.37 | 13.2 | 0.93 | 11.7 | 0.19 | 7.9 | 0.41 | 12.6 | 0.23 |
| | **M** | 14.7 | | 13.1 | | 13.0 | | 8.6 | | 13.6 | |
| **15** | **F** | 15.6 | 0.62 | 12.9 | 0.12 | 10.8 | 0.01* | 7.9 | 0.26 | 12.9 | 0.19 |
| | **M** | 16.1 | | 14.4 | | 13.8 | | 8.9 | | 14.1 | |
| **16** | **F** | 16.0 | 0.93 | 13.2 | 0.35 | 11.8 | 0.04* | 8.1 | 0.14 | 13.2 | 0.31 |
| | **M** | 15.9 | | 14.0 | | 14.0 | | 9.1 | | 14.2 | |

*P<0.05.

Table 7A. ANCOVA Showing Change in Sagittal Airway Dimension with Increasing Age in Females. Change is calculated as the difference between the younger age and the older age.

| Females<br>Plane | 1A-1B | | | 2A-2B | | | 3A-3B | | | 4A-4B | | | 5A-5B | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Age** | **Mean** | **Change** | **P-value** | **Mean** | **Change** | **P-value** | **Mean** | **Change** | **P-value** | **Mean** | **Change** | **P-value** | **Mean** | **Change** | **P-value** |
| **7** | 13.9 | 0.7 | 1.0 | 12.1 | 0.2 | 1.0 | 11.3 | 0.0 | 1.0 | 7.7 | 0.1 | 1.0 | 11.3 | 0.0 | 1.0 |
| **8** | 13.2 | -1.5 | 1.0 | 11.9 | -0.8 | 1.0 | 11.3 | 0.1 | 1.0 | 7.6 | -0.7 | 1.0 | 11.3 | -0.4 | 1.0 |
| **9** | 14.7 | -0.7 | 1.0 | 12.7 | -0.3 | 1.0 | 11.2 | -0.9 | 1.0 | 8.3 | 0.9 | 1.0 | 11.7 | -0.1 | 1.0 |
| **10** | 15.4 | 0.3 | 1.0 | 13.0 | 0.5 | 1.0 | 12.1 | 0.5 | 1.0 | 7.4 | -0.4 | 1.0 | 11.8 | -0.6 | 1.0 |
| **11** | 15.1 | 0.5 | 1.0 | 12.5 | 0.1 | 1.0 | 11.6 | 0.6 | 1.0 | 7.8 | 0.6 | 1.0 | 12.4 | 0.2 | 1.0 |
| **12** | 14.6 | -1.2 | 1.0 | 12.4 | -0.7 | 1.0 | 11.0 | -0.2 | 1.0 | 7.2 | -0.6 | 1.0 | 12.2 | -0.5 | 1.0 |
| **13** | 15.8 | 0.2 | 1.0 | 13.1 | -0.1 | 1.0 | 11.2 | -0.5 | 1.0 | 7.8 | -0.1 | 1.0 | 12.7 | 0.1 | 1.0 |
| **14** | 15.6 | 0.0 | 1.0 | 13.2 | 0.3 | 1.0 | 11.7 | 0.9 | 1.0 | 7.9 | 0.0 | 1.0 | 12.6 | -0.3 | 1.0 |
| **15** | 15.6 | -0.4 | 1.0 | 12.9 | -0.3 | 1.0 | 10.8 | -1.0 | 1.0 | 7.9 | -0.2 | 1.0 | 12.9 | -0.3 | 1.0 |
| **16** | 16.0 | | | 13.2 | | | 11.8 | | | 8.1 | | | 13.2 | | |
| **7 to 16** | | -2.1 | 0.66 | | -1.1 | 1.0 | | -0.5 | 1.0 | | -0.4 | 1.0 | | -1.9 | 0.53 |

*P<0.05.

Table 8. ANCOVA Showing Change in Sagittal Airway Dimension with Increasing Age in Males. Change is calculated as the difference between the younger age and the older age.

| Males<br>Plane | 1A-1B | | | 2A-2B | | | 3A-3B | | | 4A-4B | | | 5A-5B | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Age** | **Mean** | **Change** | **P-value** | **Mean** | **Change** | **P-value** | **Mean** | **Change** | **P-value** | **Mean** | **Change** | **P-value** | **Mean** | **Change** | **P-value** |
| **7** | 12.5 | -0.7 | 1.0 | 10.8 | -0.8 | 1.0 | 12.9 | 0.1 | 1.0 | 7.8 | 0 | 1.0 | 11.2 | -0.9 | 1.0 |
| **8** | 13.2 | 0.2 | 1.0 | 11.6 | -0.2 | 1.0 | 12.8 | 0.7 | 1.0 | 7.8 | -0.6 | 1.0 | 12.1 | -0.2 | 1.0 |
| **9** | 13 | -0.8 | 1.0 | 11.8 | -0.6 | 1.0 | 12.1 | 0 | 1.0 | 8.4 | 0.2 | 1.0 | 12.3 | 0.1 | 1.0 |
| **10** | 13.8 | -0.8 | 1.0 | 12.4 | -0.5 | 1.0 | 12.1 | -0.3 | 1.0 | 8.2 | 0.2 | 1.0 | 12.2 | -0.4 | 1.0 |
| **11** | 14.6 | -0.2 | 1.0 | 12.9 | -0.3 | 1.0 | 12.4 | 0.2 | 1.0 | 8 | 0.2 | 1.0 | 12.6 | 0.3 | 1.0 |
| **12** | 14.8 | -0.3 | 1.0 | 13.2 | -0.4 | 1.0 | 12.2 | -1.6 | 1.0 | 7.8 | -0.9 | 1.0 | 12.3 | -0.6 | 1.0 |
| **13** | 15.1 | 0.4 | 1.0 | 13.6 | 0.5 | 1.0 | 13.8 | 0.8 | 1.0 | 8.7 | 0.1 | 1.0 | 12.9 | -0.7 | 1.0 |
| **14** | 14.7 | -1.4 | 1.0 | 13.1 | -1.3 | 1.0 | 13 | -0.8 | 1.0 | 8.6 | -0.3 | 1.0 | 13.6 | -0.5 | 1.0 |
| **15** | 16.1 | 0.2 | 1.0 | 14.4 | 0.4 | 1.0 | 13.8 | -0.2 | 1.0 | 8.9 | -0.2 | 1.0 | 14.1 | -0.1 | 1.0 |
| **16** | 15.9 | | | 14 | | | 14 | | | 9.1 | | | 14.2 | | |
| **7 to 16** | | -3.4 | 0.09 | | -3.2 | 0.04* | | -1.1 | 1.0 | | -1.3 | 0.99 | | -3.0 | 0.03* |

*P<0.05.

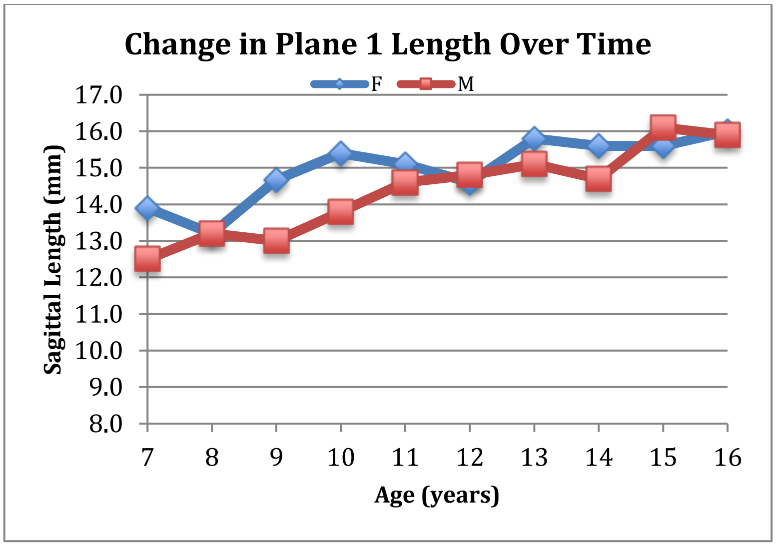


Figure 2. Estimated Marginal Means of Sagittal Airway Dimension on Plane 1.

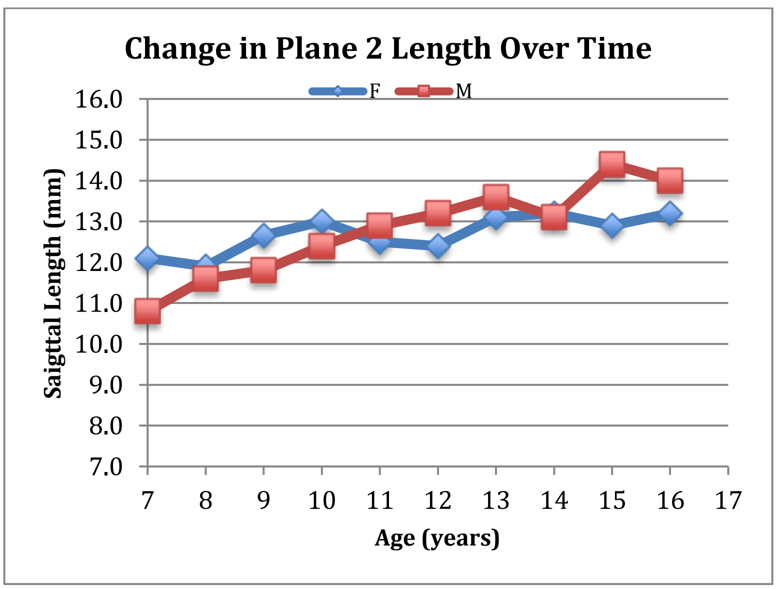


Figure 3. Estimated Marginal Means of Sagittal Airway Dimension on Plane 2.

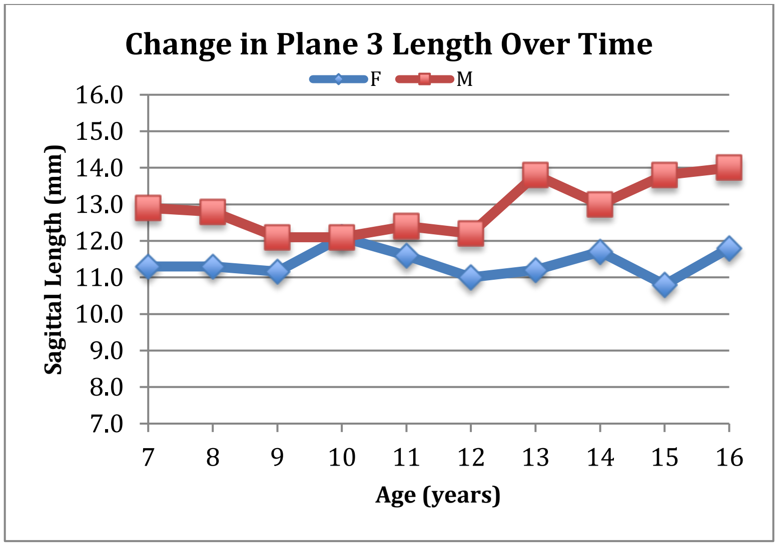


Figure 4. Estimated Marginal Means of Sagittal Airway Dimension on Plane 3.

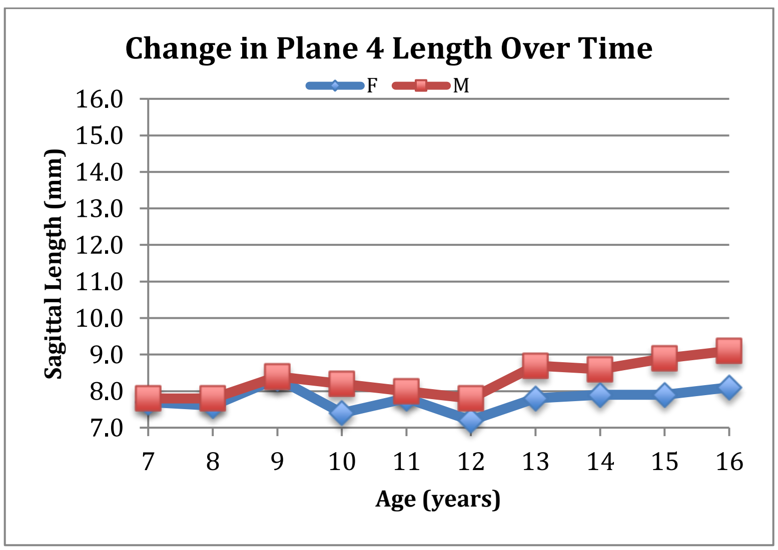


Figure 5. Estimated Marginal Means of Sagittal Airway Dimension on Plane 4.

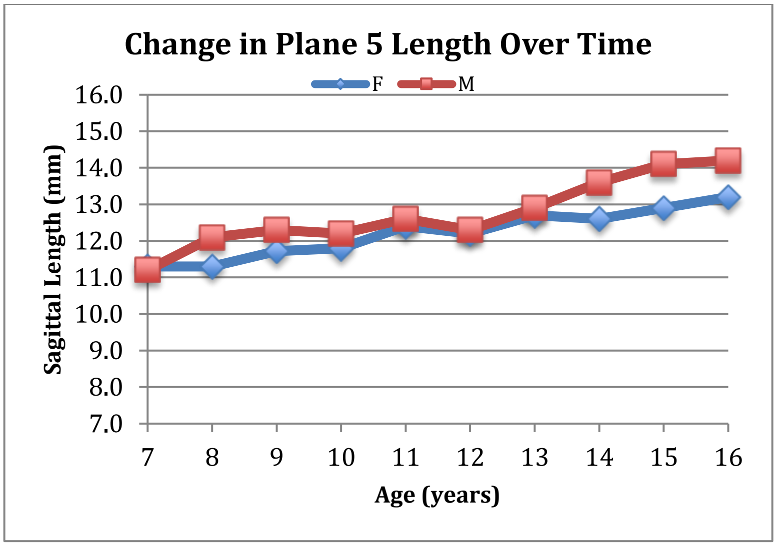


Figure 6. Estimated Marginal Means of Sagittal Airway Dimension on Plane 5.

The estimated marginal means with 95% confidence intervals and standard error for each sagittal airway dimension at each of the five planes, after controlling for location, are shown in Appendix C and Figures 2-6. In all five planes, there was an increase in sagittal dimension with increasing age.

The total change in TFH between age 7 and 16 is shown in Appendix D. The greatest change between age 7 and 16 was 2.8°. Facial type did not change by more than 1 standard deviation for any patient.

## Discussion

### *Effect of Location on Sagittal Airway Dimension*

Epigenetic effects may have partially accounted for statistically significant differences in sagittal airway dimensions among the four locations. All patients in this study were Caucasian, but the country of origin was not specified. Genetics can be a strong etiological factor in upper airway soft tissue dimensions and thus sagittal upper airway dimension.[10,11]

The time at which each study collected cephalograms differed among locations. The Bolton-Brush study was conducted between 1930-1950, the Denver study between 1927-1967, the Michigan study between 1953-1970, and the Oregon study between early 1950s-mid-1970s. The environment, which includes air pollutants, allergens, and irritants, can affect upper airway soft tissue dimensions.[12,13] Therefore, it is possible that the environment changed with time.

All radiographs were scaled according to the AAOF Scaled Measurements Guide, but differences in radiographic technique may have contributed to the differences in sagittal airway dimensions based on location. The AAOF accounted for the mid-sagittal plane to film distances among the different locations accordingly with location-specific magnification factors, but it is difficult to ensure that the position of every subject was standardized and consistent throughout the collection of all cephalograms.

### *Gender and Sagittal Airway Dimension*

While some studies have shown differences in dentofacial and craniofacial growth characteristics between males and females,[14,15] this study showed that there was generally no statistically significant difference between males and females in sagittal airway dimension at any given age, with the exception of males having greater 3A-3B than females at ages 13, 15, and 16. This supports other airway studies having shown that little to no difference between males and females at any age.[3,5,10,16] This lack of sexual dimorphism between males and females in sagittal airway dimension may explain why females have a lower incidence of obstructive sleep apnea than males. Since females are generally smaller in stature than males yet have equal sagittal airway dimension, females might have a relatively larger sagittal airway dimension when compared to their general body size.[3] More studies are needed to test this observation. The comparison of the overall trend of increasing sagittal airway dimension in males and females with increasing age suggests that while female growth occurs earlier than males in early adolescence, males eventually outgrow females.[17]

### *Age and Sagittal Airway Dimension*

A small absolute increase in sagittal airway dimension between age 7 and 16 is in agreement with other studies.[3,11,22] In a retrospective cross-sectional study, Mislik et al.[11] found that the shortest distance between posterior pharyngeal wall and the soft palate (upper airway) increased 1.03 mm between 6 and 17 years of age. The trend of increasing sagittal upper airway dimension with increasing age could be attributed to the shrinking lymphoid tissues, continued growth of the pharynx, and forward drift of the palate with increasing age.[3,5,18] Other factors contributing to lower sagittal airway dimension includes tongue position, absence or presence of enlarged palatine tonsils, forward position of the hyoid bone, and forward translation of the mandible.[19]

The relatively small increase between ages 7 and 16 in sagittal airway dimension suggests that the majority of pharyngeal growth occurs early in childhood and that comparatively less growth occurs with increasing age in adolescence.[3,20] Thus, it may be important to screen for constricted airways in early childhood to encourage the airway to develop normally during the critical period before adolescence.

Total face height change between 7 to 16-years-old was no greater than 2.7° for any patient, and facial type also did not change more than 1 standard deviation (Appendix 1). These findings appear consistent with Bishara's et al. conclusion that 77% of people have the same facial type at age 5 and 25.5 years of age.[14]

### *Significance of Mean Changes*

Sagittal airway dimension is highly individualistic and depends on a number of factors including the size and shape of the lymphoid, adenoids, tonsils, soft palate, and the soft tissues surrounding the airway,[12,21] which supports the high interindividual variation in sagittal airway dimension seen in this study. Thus, the estimated marginal means should be interpreted with caution.

### *Clinical Significance*

Although the results were not statistically significant for all measurements, clinical significance may be noted. Any increase in sagittal airway dimension could have a noticeable impact on function. The Hagan-Poiseuille equation postulates that flow varies with the fourth power of the diameter in a rigid tube. However, the pharyngeal airway is not rigid and is influenced by many other anatomical structures within and surrounding the pharyngeal airway. Thereby, a seemingly small increase in sagittal airway dimension might result in a significant increase in airflow.

In Vinoth et al.'s study,[22] a twin-block appliance used in 11-13 years old for 14.5 months produced a statistically significant increase in both upper and lower airway on the sagittal plane by 1.08 and 1.62 mm after 14.5 months, respectively. The absolute difference between pre and post twin-block therapy of 1.08 and 1.62 mm in upper and lower sagittal airway dimension, respectively, approximates the average differences between 7 and 16 years-old found in this study with growth. Thus, the findings of the current study suggest that the increase in sagittal airway dimension found in Vinoth et al.'s study may have been the result of normal growth rather than the twin-block appliance.

Fransson et al. found that the pharyngeal area increased in OSA patients and snorers using a mandibular positioning device (MPD) for 2 years nightly. Mean linear distance at the hypopharyngeal level increased by 2.4 mm (± 4.6 SD) for these patients in an upright position and 1.7 mm (± 4.3 SD) in a supine position.[23] In a separate study, Fransson et al.[24] also found that after 2 years of MPD appliance, 90% of patients experienced a significant reduction in snoring and apnea events, 76% experienced a reduction in daytime tiredness and 84% an improvement in quality of night sleep, which amounted to greater than 50% increase from the baseline. The OSA group's oxygen desaturation index significantly decreased from 14.7 (± 12.7 SD) to 3.1 (± 4.2 SD) and their mean SaO2 nadir increased from 78.2% (± 8.1) to 89.0% (± 4.7). This suggests that a relatively small increase in sagittal airway dimension can be clinically significant. Future studies are needed to specifically determine how much increase in sagittal airway dimension is actually clinically significant.

In a cross-sectional 3-D analysis of the pharyngeal airway, Kim et al.[25] found that the transverse dimension of the upper airway is larger than the sagittal dimension in skeletal Class 1 and Class 2 children. Thus, the transverse dimension may have a larger increase with age than the sagittal dimension. Future 3-D studies that capture the upper airway sagittal and transverse dimensions in pre-adolescence, adolescence, and adulthood may aid in the corroboration of this hypothesis.

This retrospective longitudinal study determined estimated marginal means of sagittal upper airway dimensions. Despite the lack of statistical significance, the clinical implications of this study may aid in the early diagnoses of constricted airways.

## Conclusions

1. Males had a statistically significant greater 3A-3B length than females at age 13 ($P$ = 0.02), 15 ($P$ = 0.01), and 16 ($P$ = 0.04).
2. In males, there was a statistically significant increase in 2A-2B ($P$ = 0.04) and 5A-5B ($P$ = 0.03) between ages 7 and 16.
3. We were unable to reject either of the null hypotheses.
4. Normative sagittal airway dimensions could not be established in this study. This study has determined average values that can be used as a general reference for sagittal airway dimensions in skeletal and dental Class 1 patients.
5. We were unable to establish normative values.

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# CHAPTER THREE

# EXTENDED DISCUSSION

## Limitations of Study and Recommendations for Future Studies

Parameters the investigator could not control that affect airway measurements include unstandardized head position[32-34], potential airway changes caused by swallowing during the radiograph, and possible differences in beam direction leading to measurement errors in an elliptical airway.[35] Future studies might control for these factors.

Resistance to airflow is affected by both the size and the shape of the pharyngeal airway.[36,37] A 2-D cephalogram cannot be used to determine the shape, transverse dimension, or volume of the airway, but neither does a 3-D CBCT depict all the true clinical variations. The radiographic depiction of the airway is affected by whether the patient is upright or supine, is awake or asleep, is inhaling or expiring, or has the mouth open or closed during radiographic exposure, and by radiographic machinery and technique, and all are susceptible to variation in capturing both the 2-D cephalogram and the 3-D CBCT. Past studies have shown that only the smallest cross-sectional area (i.e. the anterior-posterior dimension) is significantly different between OSA and non-OSA patients.[11,38] Thus, the anterior-posterior dimension captured in a 2-D cephalogram is clinically relevant.

Past studies have suggested that an sagittal upper airway dimension less than 5 mm is considered constricted and a lower sagittal airway dimension greater than 15 mm is likely due to the habit of an anteriorly placed tongue or enlarged tonsils.[39] While the results of this study cannot be used to establish definitive criteria of a constricted or normal airway, future studies can measure sagittal airway dimensions in dental and skeletal Class 1 children and adolescents diagnosed with OSA and thus determine if values deviate from the average sagittal airway dimensions found in this study.

Longitudinal studies provide more accurate analysis growth trends than cross-sectional studies.[40] Using CBCT in a longitudinal study with a greater number of patients with longitudinal cephalograms from 7 to 16 years old is unfeasible for future studies. Thus, future studies can create a predictive regression analysis utilizing the measurements found in this study to determine whether skeletal and dental Class 1 patients without any diagnosed airway issues conform to the predictive model.

Computational modeling of the pharyngeal airway using finite element analysis has been shown to be effective in predicting surgical success in OSA patients. [41,42] Future studies can utilize computational modeling of the airway by digitally altering the pharyngeal airway to match the average values found in this study, and then superimpose the cephalograms of Class 1 skeletal and dental patients to determine if and how much they deviate from the computational model.

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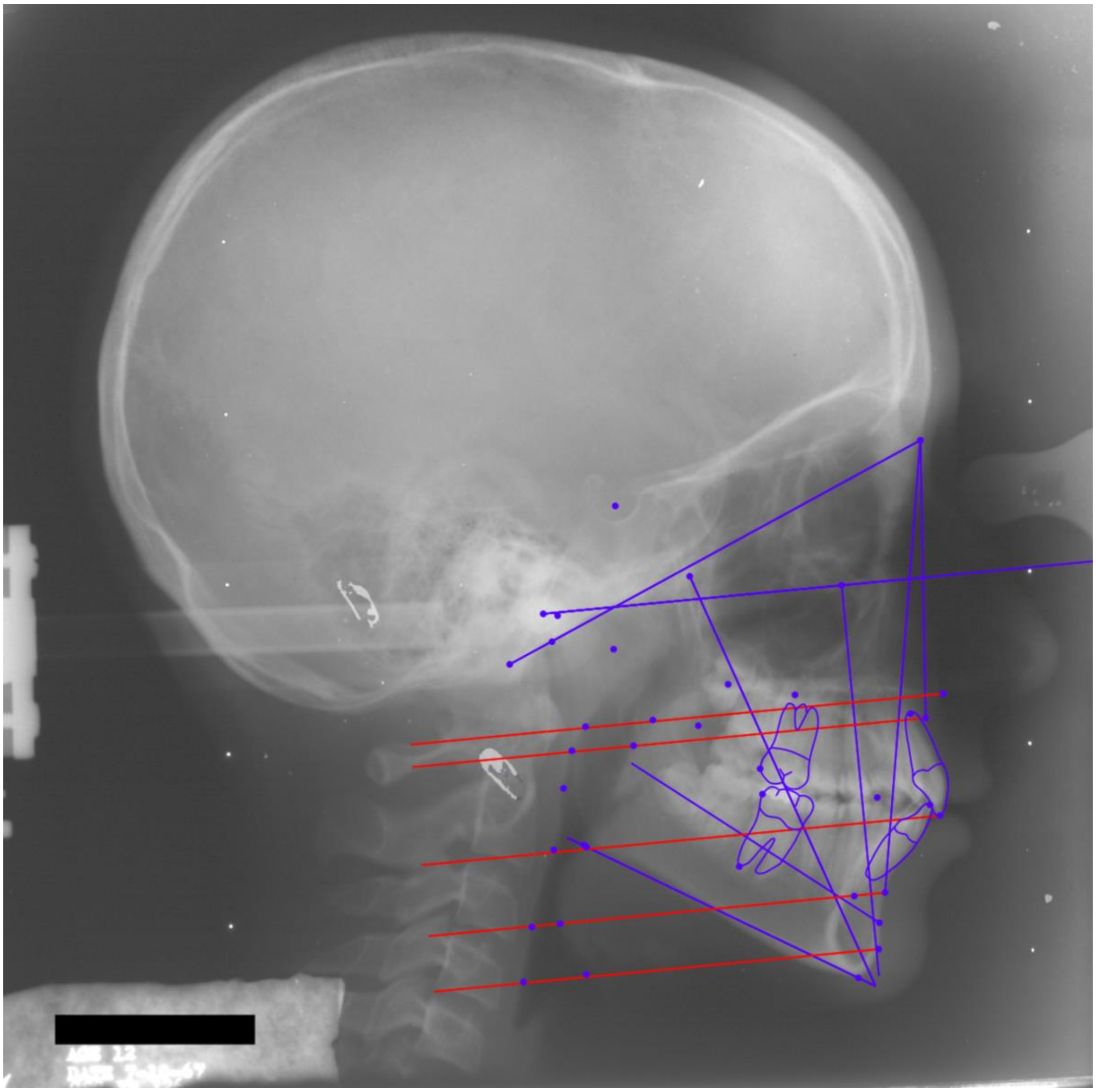
## APPENDIX A

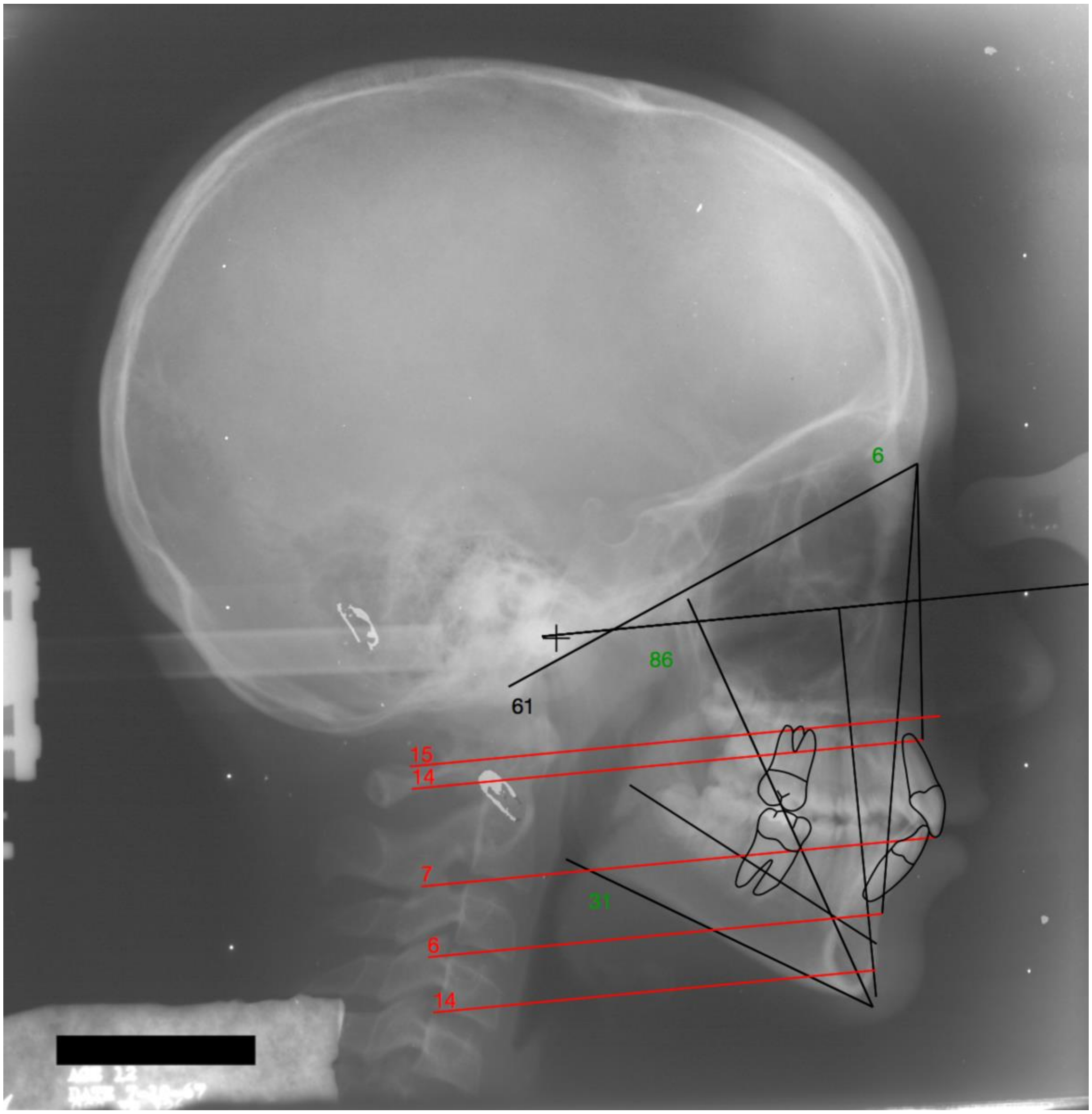
## DIGITAL TRACING OF LANDMARKS ON SUBJECT 121-1 AT 12-YEARS-OLD



**APPENDIX B**

**SAGITTAL AIRWAY DIMENSION AND FACIAL TYPE MEASUREMENTS ON**

**SUBJECT 121-1**



## APPENDIX C

## ESTIMATED MARGINAL MEANS AND 95% CONFIDENCE INTERVALS OF SAGITTAL AIRWAY DIMENSIONS ON PLANES 1-5

| Plane | | 1A-1B | | | |
|---|---|---|---|---|---|
| Age | Gender | Mean | Std. Error | 95% Confidence Interval | |
| | | | | Lower Bound | Upper Bound |
| 7 | F | 13.9 | 0.6 | 12.6 | 15.1 |
| | M | 12.5 | 0.6 | 11.2 | 13.7 |
| 8 | F | 13.2 | 0.7 | 11.9 | 14.6 |
| | M | 13.2 | 0.7 | 11.8 | 14.6 |
| 9 | F | 14.7 | 0.8 | 13.2 | 16.2 |
| | M | 13.0 | 0.7 | 11.6 | 14.4 |
| 10 | F | 15.4 | 0.8 | 13.9 | 17.0 |
| | M | 13.8 | 0.8 | 12.2 | 15.4 |
| 11 | F | 15.1 | 0.7 | 13.6 | 16.6 |
| | M | 14.6 | 0.7 | 13.1 | 16.1 |
| 12 | F | 14.6 | 0.8 | 13.1 | 16.2 |
| | M | 14.8 | 0.8 | 13.2 | 16.3 |
| 13 | F | 15.8 | 0.7 | 14.3 | 17.3 |
| | M | 15.1 | 0.8 | 13.5 | 16.7 |
| 14 | F | 15.6 | 0.7 | 14.2 | 17.1 |
| | M | 14.7 | 0.7 | 13.2 | 16.2 |
| 15 | F | 15.6 | 0.8 | 14.0 | 17.2 |
| | M | 16.1 | 0.7 | 14.6 | 17.6 |
| 16 | F | 16.0 | 0.8 | 14.5 | 17.5 |
| | M | 15.9 | 0.8 | 14.4 | 17.4 |

| Plane | | 2A-2B | | | |
|---|---|---|---|---|---|
| Age | Gender | Mean | Std. Error | 95% Confidence Interval | |
| | | | | Lower Bound | Upper Bound |
| 7 | F | 12.1 | 0.5 | 11.0 | 13.2 |
| | M | 10.8 | 0.6 | 9.6 | 11.9 |
| 8 | F | 11.9 | 0.6 | 10.6 | 13.1 |
| | M | 11.6 | 0.6 | 10.3 | 12.8 |
| 9 | F | 18 | 0.7 | 11.3 | 14.1 |
| | M | 11.8 | 0.7 | 10.5 | 13.1 |
| 10 | F | 13.0 | 0.7 | 11.7 | 14.3 |
| | M | 12.4 | 0.7 | 11.0 | 13.8 |
| 11 | F | 12.5 | 0.7 | 11.1 | 13.9 |
| | M | 12.9 | 0.7 | 11.5 | 14.3 |

| | | | | | |
|---|---|---|---|---|---|
| 12 | F | 12.4 | 0.7 | 11.1 | 13.8 |
| | M | 13.2 | 0.7 | 11.9 | 14.6 |
| 13 | F | 13.1 | 0.6 | 11.8 | 14.4 |
| | M | 13.6 | 0.7 | 12.2 | 15.0 |
| 14 | F | 13.2 | 0.7 | 11.8 | 14.5 |
| | M | 13.1 | 0.7 | 11.7 | 14.4 |
| 15 | F | 12.9 | 0.7 | 11.6 | 14.3 |
| | M | 14.4 | 0.6 | 13.1 | 15.7 |
| 16 | F | 13.2 | 0.6 | 11.9 | 14.5 |
| | M | 14.0 | 0.7 | 12.7 | 15.3 |

| Plane | | 3A-3B | | | |
|---|---|---|---|---|---|
| **Age** | **Gender** | **Mean** | **Std. Error** | **95% Confidence Interval** | |
| | | | | **Lower Bound** | **Upper Bound** |
| 7 | F | 11.3 | 0.7 | 9.9 | 12.7 |
| | M | 12.9 | 0.7 | 11.5 | 14.3 |
| 8 | F | 11.3 | 0.8 | 9.8 | 12.9 |
| | M | 12.8 | 0.8 | 11.2 | 14.3 |
| 9 | F | 11.2 | 0.9 | 9.4 | 12.9 |
| | M | 12.1 | 0.8 | 10.5 | 13.7 |
| 10 | F | 12.1 | 0.7 | 10.6 | 13.6 |
| | M | 12.1 | 0.8 | 10.5 | 13.6 |
| 11 | F | 11.6 | 0.8 | 10.1 | 13.2 |
| | M | 12.4 | 0.8 | 10.9 | 14.0 |
| 12 | F | 11.0 | 0.9 | 9.1 | 12.9 |
| | M | 12.2 | 0.9 | 10.4 | 14.1 |
| 13 | F | 11.2 | 0.7 | 9.7 | 12.7 |
| | M | 13.8 | 0.8 | 12.1 | 15.4 |
| 14 | F | 11.7 | 0.7 | 10.3 | 13.1 |
| | M | 13.0 | 0.7 | 11.6 | 14.4 |
| 15 | F | 10.8 | 0.8 | 9.2 | 12.4 |
| | M | 13.8 | 0.7 | 12.3 | 15.3 |
| 16 | F | 11.8 | 0.8 | 10.3 | 13.3 |
| | M | 14.0 | 0.8 | 12.5 | 15.6 |

| Plane | | 4A-4B | | | |
|---|---|---|---|---|---|
| **Age** | **Gender** | **Mean** | **Std. Error** | **95% Confidence Interval** | |
| | | | | **Lower Bound** | **Upper Bound** |
| 7 | F | 7.7 | 0.6 | 6.5 | 8.9 |
| | M | 7.8 | 0.6 | 6.6 | 9.0 |
| 8 | F | 7.6 | 0.5 | 6.6 | 8.6 |

| | | | | | |
|---|---|---|---|---|---|
| | **M** | 7.8 | 0.5 | 6.8 | 8.9 |
| **9** | **F** | 8.3 | 0.6 | 7.1 | 9.6 |
| | **M** | 8.4 | 0.6 | 7.2 | 9.6 |
| **10** | **F** | 7.4 | 0.5 | 6.3 | 8.5 |
| | **M** | 8.2 | 0.6 | 7.0 | 9.3 |
| **11** | **F** | 7.8 | 0.6 | 6.6 | 8.9 |
| | **M** | 8.0 | 0.6 | 6.8 | 9.1 |
| **12** | **F** | 7.2 | 0.6 | 6.1 | 8.3 |
| | **M** | 7.8 | 0.6 | 6.7 | 8.9 |
| **13** | **F** | 7.8 | 0.6 | 6.7 | 8.9 |
| | **M** | 8.7 | 0.6 | 7.5 | 10.0 |
| **14** | **F** | 7.9 | 0.6 | 6.7 | 9.1 |
| | **M** | 8.6 | 0.6 | 7.4 | 9.8 |
| **15** | **F** | 7.9 | 0.6 | 6.7 | 9.1 |
| | **M** | 8.9 | 0.6 | 7.7 | 10.0 |
| **16** | **F** | 8.1 | 0.5 | 7.0 | 9.1 |
| | **M** | 9.1 | 0.5 | 8.1 | 10.2 |

| **Plane** | | **5A-5B** | | | |
|---|---|---|---|---|---|
| **Age** | **Gender** | **Mean** | **Std. Error** | **95% Confidence Interval** | |
| | | | | **Lower Bound** | **Upper Bound** |
| **7** | **F** | 11.3 | 0.5 | 10.2 | 12.3 |
| | **M** | 11.2 | 0.5 | 10.2 | 12.3 |
| **8** | **F** | 11.3 | 0.6 | 10.0 | 12.5 |
| | **M** | 12.1 | 0.6 | 10.8 | 13.3 |
| **9** | **F** | 11.7 | 0.6 | 10.5 | 12.9 |
| | **M** | 12.3 | 0.6 | 11.2 | 13.5 |
| **10** | **F** | 11.8 | 0.5 | 10.8 | 12.8 |
| | **M** | 12.2 | 0.5 | 11.2 | 13.3 |
| **11** | **F** | 12.4 | 0.6 | 11.2 | 13.6 |
| | **M** | 12.6 | 0.6 | 11.4 | 13.9 |
| **12** | **F** | 12.2 | 0.6 | 11.1 | 13.3 |
| | **M** | 12.3 | 0.6 | 11.2 | 13.5 |
| **13** | **F** | 12.7 | 0.6 | 11.5 | 13.9 |
| | **M** | 12.9 | 0.7 | 11.6 | 14.2 |
| **14** | **F** | 12.6 | 0.6 | 11.5 | 13.8 |
| | **M** | 13.6 | 0.6 | 12.5 | 14.8 |
| **15** | **F** | 12.9 | 0.7 | 11.5 | 14.2 |
| | **M** | 14.1 | 0.6 | 12.8 | 15.4 |
| **16** | **F** | 13.2 | 0.7 | 11.9 | 14.5 |
| | **M** | 14.2 | 0.7 | 12.8 | 15.5 |

## APPENDIX D

## TFH CHANGE BETWEEN AGES 7 AND 16 YEARS-OLD

| Patient ID | Location | Age | TFH | TFH change |
|---|---|---|---|---|
| 945 | BoltonBrush | 7 | 59.8 | -1.5 |
| | | 16 | 61.3 | |
| 2817 | BoltonBrush | 7 | 54.0 | -0.1 |
| | | 16 | 54.1 | |
| 2252 | BoltonBrush | 7 | 59.5 | -1.7 |
| | | 16 | 61.2 | |
| 2140 | BoltonBrush | 7 | 53.4 | 1.6 |
| | | 16 | 51.8 | |
| 2290 | BoltonBrush | 7 | 56.7 | -1.7 |
| | | 16 | 58.4 | |
| 2425 | BoltonBrush | 7 | 59.4 | 0.5 |
| | | 16 | 58.9 | |
| 2702 | BoltonBrush | 7 | 56.4 | 1.7 |
| | | 16 | 54.7 | |
| 2398 | BoltonBrush | 7 | 56.9 | -0.1 |
| | | 16 | 57.0 | |
| 2729 | BoltonBrush | 7 | 59.4 | -1.2 |
| | | 16 | 60.6 | |
| 510 | Denver | 7 | 55.7 | 1.9 |
| | | 16 | 53.8 | |
| 515 | Denver | 7 | 56.8 | 3 |
| | | 16 | 54.0 | |
| 535 | Denver | 7 | 57.2 | 1.8 |
| | | 16 | 55.4 | |
| 557 | Denver | 7 | 60.3 | 1.8 |
| | | 16 | 58.5 | |
| 616 | Denver | 7 | 59.4 | -2.5 |
| | | 16 | 61.9 | |
| 626 | Denver | 7 | 59.1 | 0.9 |
| | | 16 | 58.2 | |
| 522 | Denver | 7 | 57.8 | 2.8 |
| | | 16 | 55.0 | |
| 552 | Denver | 7 | 57.6 | -0.5 |
| | | 16 | 58.1 | |
| 563 | Denver | 7 | 54.0 | 0.2 |
| | | 16 | 53.8 | |

| | | | | |
|---|---|---|---|---|
| 72 | Denver | 7 | 63.3 | -0.4 |
| | | 16 | 63.7 | |
| 73 | Denver | 7 | 61.0 | -0.9 |
| | | 16 | 61.9 | |
| 98 | Denver | 7 | 64.3 | -0.5 |
| | | 16 | 64.8 | |
| 111 | Denver | 7 | 58.4 | 1.7 |
| | | 16 | 56.7 | |
| 87 | Denver | 7 | 61.5 | -1.4 |
| | | 16 | 62.9 | |
| 110 | Denver | 7 | 54.1 | 2.3 |
| | | 16 | 51.8 | |
| 1872 | Michigan | 7 | 57.7 | 2.5 |
| | | 16 | 55.2 | |
| 1891 | Michigan | 7 | 64.0 | -2.6 |
| | | 16 | 66.6 | |
| 2026 | Michigan | 7 | 53.2 | 2.8 |
| | | 16 | 50.4 | |
| 2108 | Michigan | 7 | 67.7 | -0.7 |
| | | 16 | 68.4 | |
| 2124 | Michigan | 7 | 59.1 | 0.2 |
| | | 16 | 58.9 | |
| 2399 | Michigan | 7 | 56.0 | -0.6 |
| | | 16 | 56.6 | |
| 2411 | Michigan | 7 | 56.3 | -0.7 |
| | | 16 | 57.0 | |
| 2549 | Michigan | 7 | 55.2 | -2.1 |
| | | 16 | 57.3 | |
| 2580 | Michigan | 7 | 60.5 | 2.7 |
| | | 16 | 57.8 | |
| 2802 | Michigan | 7 | 59.9 | 1.5 |
| | | 16 | 58.4 | |
| 2008 | Michigan | 7 | 60.6 | -2.7 |
| | | 16 | 63.3 | |
| 2560 | Michigan | 7 | 59.1 | -1.1 |
| | | 16 | 60.2 | |
| 2679 | Michigan | 7 | 59.3 | -1.7 |
| | | 16 | 61.0 | |
| 1890 | Michigan | 7 | 62.7 | -1.8 |
| | | 16 | 64.5 | |
| 2196 | Michigan | 7 | 60.1 | -0.1 |

| | | | | |
|---|---|---|---|---|
| | | 16 | 60.2 | |
| 2286 | Michigan | 7 | 60.5 | -2.2 |
| | | 16 | 62.7 | |
| 2449 | Michigan | 7 | 49.3 | 1 |
| | | 16 | 48.3 | |
| 105-1 | Oregon | 7 | 58.7 | 2.1 |
| | | 16 | 56.6 | |
| 105-2 | Oregon | 7 | 59.1 | 1.5 |
| | | 16 | 57.6 | |
| 123-1 | Oregon | 7 | 63.2 | -1.5 |
| | | 16 | 64.7 | |
| 183-1 | Oregon | 7 | 62.2 | -1.9 |
| | | 16 | 64.1 | |
| 183-2 | Oregon | 7 | 61.6 | -2 |
| | | 16 | 63.6 | |
| 295 | Oregon | 7 | 56.4 | -1.3 |
| | | 16 | 57.7 | |
| 89-2 | Oregon | 7 | 58.3 | 0.6 |
| | | 16 | 57.7 | |
| 76 | Oregon | 7 | 59.4 | -1.6 |
| | | 16 | 61.0 | |
| 77 | Oregon | 7 | 57.1 | 1.8 |
| | | 16 | 55.3 | |
| 83-2 | Oregon | 7 | 60.4 | -1.1 |
| | | 16 | 61.5 | |
| 100-1 | Oregon | 7 | 60.3 | -1.1 |
| | | 16 | 61.4 | |
| 109-1 | Oregon | 7 | 56.2 | 1.3 |
| | | 16 | 54.9 | |
| 121-1 | Oregon | 7 | 67.7 | 1.4 |
| | | 16 | 66.3 | |
| 121-2 | Oregon | 7 | 70.6 | -1.5 |
| | | 16 | 72.1 | |
| 150-1 | Oregon | 7 | 57.4 | -1.8 |
| | | 16 | 59.2 | |
| 241-2 | Oregon | 7 | 58.2 | -2.5 |
| | | 16 | 60.7 | |
| 248 | Oregon | 7 | 52.0 | 1.4 |
| | | 16 | 50.6 | |
| 15 | Oregon | 7 | 65.2 | 1.3 |
| | | 16 | 63.9 | |
| 83-1 | Oregon | 7 | 60.0 | -0.6 |
| | | 16 | 60.6 | |
| 132 | Oregon | 7 | 55.7 | -1.5 |

| | | | | |
|---|---|---|---|---|
| | | 16 | 57.2 | |
| 247 | Oregon | 7 | 56.5 | 1.8 |
| | | 16 | 54.7 | |