A Longitudinal Assessment of the Retromolar Space

BY

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THESIS

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This thesis is dedicated to my family for their unconditional support every step of this journey.

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SUMMARY

Mandibular third molar development begins in the ramus area at around 7 years old (Banks 1934). At that early stage, the space needed for their eventual eruption is not yet completely available. Investigators have defined the retromolar space as the distance between the distal surface of the lower 2nd or 1st molar crown and the anterior border of the ramus (Ghougassian and Ghafari 2014; Truong et al. 2016; Bjork, Jensen, and Palling 1956). The insufficient space in the retromolar area is a major cause of lower third molar impactions (Zelic and Nedeljkovic 2013; Abu Alhaija, AlBhairan, and AlKhateeb 2011).

The current retrospective study was performed using data collected from de-identified lateral cephalometric radiographs of Caucasian individuals from the Denver, Iowa and Oregon growth studies. These studies are publicly available from the American Association of Orthodontists Foundation Craniofacial Growth Legacy Collection. The retromolar space was measured on lateral cephalometric radiographs of subjects taken at approximately 8,10,12,14 and, if available, at 18 years old (within 6 months of each age point).

Radiographs from subjects at the approximately 18 year old time point with developing lower third molars were classified using the Pell and Gregory classification system, an established method for evaluating the level of difficulty of third molar extraction. The teeth were evaluated based on the overlap between the anterior border of the ramus and the third molar. It also takes into consideration the depth of the impaction in relation to the lower second molar.

SUMMARY (continued)

Subjects with compromised quality or distortion of the radiograph, history of orthodontic treatment or dental extraction, congenitally missing teeth, incomplete set of cephalometric radiographs (not including age 18), or radiographs taken at incorrect time points were excluded from the study. A total of 99 total subjects, 56 males and 43 females, were included the sample. 41 subjects, which included 24 females and 17 males had developing mandibular third molars radiographically visible at age 18. The subjects ranged from ages 8-18 years old.

Six landmarks were identified on each subject's lateral cephalometric radiograph. These landmarks were used to evaluate the growth changes of the retromolar space in relation to the occlusal plane. The digital landmarking was completed using Dolphin Imaging™ software (Version 11.95 Premium Dolphin Imaging Systems LLC, Chatsworth, LA).

Our current study revealed that the average retromolar space increased 8.73mm from 8 to 18 years old. A series of t-tests and Wilcoxon rank sum tests failed to find a statistically significant difference in retromolar space size between males and females. Repeated measures ANOVA and linear fixed effects model revealed that the trend of growth is slightly different in that females tend to have larger retromolar spaces through age 12. Females show more growth earlier but a younger cessation. At Age 14, both sexes diverge, with males showing larger magnitude of growth going forward.

SUMMARY (continued)

A repeated measures ANOVA also failed to find a statistically significant difference in retromolar space by 3rd molar classification. However, there is a non-significant trend towards larger retromolar spaces in patients with Class 1A/1B third molars. Future studies with larger sample sizes at our final time-point (age 18) might help to clarify this relationship.

Finally, previous studies on the growth of the retromolar space are very limited, our findings add to the body of literature establishing the typical amount of retromolar space growth to be expected at a given age.

I. INTRODUCTION

1.1 **Background**

It is known that growth in length of the body of the mandible is a result of resorption of the anterior border of the ramus and apposition on the posterior side. This leads to a backward translation of the ramus in conjunction with the growth in length of the body of the mandible (Enlow, Moyers, and Merow 1982). During growth, it is important that this backward movement of the ramus occurs in order for the jaw to accommodate the posterior teeth that are in development (Bjork 1969).

The increase in the retromolar space with time has been attributed to various factors, such as the resorption of bone at the anterior aspect of the ramus, the forward movement of the teeth, the increase in length of the mandible due to growth, the mandibular growth pattern and eruption of the teeth in sagittal direction and the presence of a backward slope of the anterior part of the ramus relative to the alveolar border (Richardson 1987).

Furthermore, the crown dimension of the lower third molar should be smaller in size mesiodistally than the space available if eruption of those teeth is expected (Ganss et al. 1993) . However, it is commonly seen that a shortage of space in that area is a major cause of lower 3rd molar impactions (Zelic and Nedeljkovic 2013; Abu Alhaija, AlBhairan, and AlKhateeb 2011). This is when space management, with or without extraction, becomes a key element.

Previous studies on the retromolar space have used lateral cephalometric radiographs to measure the retromolar space from the distal surface of the lower terminal molar to the anterior border of the ramus, based upon the methods used by Chen et al. (Chen et al. 2010) and Ganss et al. (Ganss et al. 1993). Chen et al. (2010) support that measuring the retromolar space along the plane of occlusion is useful for evaluating the probability of impaction or eruption of the third molars. Behbehani et al. (2006) used the same type of radiographic image, however they believed the Rickett's Xi point (a point that is constructed and located at the center of the ascending ramus, which is approximately at the level of the inferior alveolar foramen) instead of the border of the ramus was a better landmark to use to evaluate the retromolar space as an appropriate predictor of third molar eruption. Their rationale was that it is sometimes hard to see the exact border of the ramus on cephalometric radiographs due to the presence of double contours resulting from the projection of both right and left sides. This may add an extra level of complexity and accuracy increasing the risk of method error (Behbehani, Artun, and Thalib 2006).

Other researchers have used different lines of reference and cephalometric planes to evaluate change in growth of the posterior space in the lower arch. Sable and Woods used Rickett's cephalometric analysis (Ricketts 1975; Ricketts 1961; Ricketts 1981) to evaluate the change in the space distal to the mandibular first permanent molar by measuring along the corpus axis by creating a tangent line starting from the distal point of convexity of the molar perpendicular to Rickett's corpus axis and evaluating this distance to Xi point (Sable and Woods 2004).

1.2 **Objective**

This study aims to examine growth of the retromolar space in a large, longitudinal dataset and to evaluate the position of the third molar in relation to that space.

1.3 **Null Hypotheses**

H_0: There is no difference in growth trend of the retromolar space between males and females.

H_0: There is no difference in growth trend of the retromolar space across third molar classification groups.

II. BACKGROUND

Growth of the retromolar space – the area between the distal of the terminal molar and the anterior surface of the ramus—throughout puberty is largely thought to exist in order to accommodate the eruption of the molars (Bjork, Jensen, and Palling 1956). Scholars have therefore long sought to identify the patterns and predictability of this growth in order to better manage treatment in cases where decisions are being made regarding extraction of teeth (Brezulier, Fau, and Sorel 2017; Zelic and Nedeljkovic 2013). An understanding of the development, impaction, and treatment of third molars is important to addressing the question of the amount of growth of the retromolar space. This section outlines the prior literature on retromolar space growth.

There has been some debate about methods for assessing retromolar space. Some studies have used the rotational tomogram to evaluate the available space. Ganss et al. (1993) compared that method to the use of lateral cephalometric radiographs to identify the threshold value for the eruption of third molars, and concluded a significant correlation between the measurements of both approaches (Ganss et al. 1993). However, Chen et al. (2010) believe that due to projection angles that can vary significantly, cephalometric radiographs may perform better than the rotational tomogram due to reduced distortion and magnification (Chen et al. 2010).

Moreover, Al-Gunaid et al. (2019) state that better measurements can be obtained with panoramic radiographs considering it may be easier to locate the contours of the ramus without double images of the right and left sides in projection. As a result, there is less method error (Al-Gunaid et al. 2019). On the contrary, another author believes there is more distortion with panoramic radiographs. This will inevitably result in linear measurements that are unreliable (Ghougassian and Ghafari 2014).

2.1 Third Molar Development

Initial radiographic evidence of third molars can be as early as 5 years old and as late as 16 years old. Their eruption time can usually vary between 18 and 24 years old (Elsey and Rock 2000), but in rare circumstances, this may occur later in life. Their development or absence from the dentition is linked to genetically predetermined dental and skeletal factors (Almpani and Kolokitha 2015). Various eruption times have been reported in the literature. For example, Fanning (1962) found a mean age of eruption of 20.4 years in women, and 19.8 years in men (Fanning 1962), Haralabakis (1957) reported a mean age of 24 years (Haralabakis 1957) while Hellman (1936) reported a mean age of 20.5 years (Hellman 1936).

Due to the wide range of mean eruption ages of the third molars, it becomes clinically irrelevant to focus on this variable as the most clinically significant in predicting whether the third molars are likely to erupt or remain impacted. Rate of impaction varies significantly from 9.5%-39% between various studies (Richardson 1992). This variability can be attributed to population differences and differences in the definition of impacted teeth, methods of diagnosis, and age of eruption among these populations (Richardson 1992).

Third molars are the most common impacted teeth (Andreasen 1997; Bishara 1999). Up to 98% of third molars show some form of delay in eruption (impaction)(Alling and Catone 1993). Third molar management is certainly a challenge that orthodontists can encounter clinically during the treatment of patients, especially in teenagers (Bishara 1999), which is complicated by the fact that their eruption is considered to be an unpredictable event (Richardson 1992). Impactions, either “potential” or “true”, are often difficult to classify.

The lower third molar crypts starts its initial development at a superior position in the angle formed by the mandibular body and ramus. During growth, these teeth often remain at the same angle relative to the mandibular body as their initial formation, which puts them in an unfavorable position for eruption (Banks 1934). Conversely, if the third molar is positioned at a favorable angle relative to the longitudinal axis of the second molar and the mandibular plane, the adequate forces required for expansion and remodeling will remain in the mandibular ramus area (Turkoz and Ulusoy 2013). Alternatively, third molars may initially develop in a favorable position but end up impacted due to a lack of mandible growth and development. Rarely, teeth that initially appear to be impacted due to an unfavorable position may develop into a position where they will erupt into the permanent dentition (Banks 1934).

The evaluation of the available space in the dentition is important for proper diagnosis and treatment planning in orthodontics. Third molars are sometimes excluded from the treatment plan due to the assumption that they will not erupt, which is an indication for extraction. However, it is important to remember that teeth should be conserved unless otherwise indicated in order to keep optimal masticatory function (Mendoza-Garcia et al. 2017).

Some consider space evaluation as a valuable tool for orthodontists to determine ahead of time whether there will be enough space for the third molar to develop and erupt. It would certainly be beneficial if the orthodontist could predict the probability of third molar eruption at an early age (Chen et al. 2010; Zelic and Nedeljkovic 2013). Some of the important key elements that need to be evaluated include the morphologic factors that favor or prevent the eruption of the third molars, the predictability, at an early age, of the space available and their final position in the arch (Chen et al. 2010; Zelic and Nedeljkovic 2013).

2.2 **Extraction vs Non Extraction**

Every year, 10 million third molars are extracted from 5 million people in the United States (Friedman 2007). This procedure is one of the most common surgeries performed by oral and maxillofacial surgeons (Friedman 2007). Since no validated model to predict impaction exists, the ideal timing of when or whether third molars should be extracted is still under debate (Normando 2015). There is currently no evidence to either refute or support the extraction of asymptomatic and non-pathological third molars (Costa et al. 2013; Mettes et al. 2012).

A prospective study (Cunha-Cruz et al. 2014) concluded that 59% of the participants were recommended by general dentists to proceed with prophylactic extraction of their third molars. The majority of those teeth were asymptomatic. The rationale behind prophylactic extractions was to prevent potential development of issues such as pathology or impaction (Cunha-Cruz et al. 2014). It is important to note that extractions involve potential risks and complications such as neurosensory disturbance, bleeding, infection, pain, and edema. Though the rate of complications varies in the literature, it has been reported to be as high as 21% (Bruce, Frederickson, and Small 1980).

While extracting impacted third molars in older patients can be complex, and carry its own set of risk factors related to this population, some believe the extraction of the third molars in development at around 7 to 10 years of age is more atraumatic and carries a lower overall risk (Ricketts et al. 1976). A retrospective cohort study evaluated the indications for maintaining third molars, which include: favorable eruption into occlusion (31%), preference of the patient (31.5%) and asymptomatic teeth (17.5%). It is important to note that advanced age and health status of patients were also often considered to be significant factors (Lieselotte et al. 2019).

Normando (2015) also highlighted the importance of having justifiable reasons when choosing to extract third molars. Surgical, periodontal, prosthetic, and orthodontic variables should be considered (Normando 2015). Scholars such as Zelic and Nedeljkovic (2013) have stressed that the decision whether to extract or not extract third molars in teenagers should be made very carefully since more available space was noted in older patients (Zelic and Nedeljkovic 2013). Indeed, when it comes to space management in the dental arch, Ledyard (1953) found that in cases with a history of orthodontic treatment, the extractions of teeth such as premolars allow the buccal segments to drift mesially, creating an expansion of the retromolar space for third molars to erupt (Ledyard 1953). Additionally, dental extractions as part of an orthodontic plan was shown to increase the chance of lower third molar eruption as more space is created (Faubion 1968). For Bjork et al. (1956), it appears obvious that for cases where the third molars are impacted, the retromolar space is markedly reduced. More specifically, the authors' study revealed that the retromolar space was significantly reduced in 90% of cases of bilateral impacted lower third molars (Bjork, Jensen, and Palling 1956). Taken together, this prior work demonstrates why the retromolar space is relevant to the decision of whether or not to proceed with dental extractions.

2.3 Factors Contributing to Impaction and Eruption

In the past, various attempts have been made to determine the factors that help predict eruption or impaction of third molars, however those results were considered inconclusive (Richardson 1977; Venta and Schou 2001). The exact etiology of tooth impaction has not been completely explained, however the consensus is that one of the main factors is the lack of space (Richardson 1977).

Kahl et al. (1994) stated that 97.4% of impacted teeth had insufficient space for eruption (Kahl, Gerlach, and Hilgers 1994). Multiple authors agree that insufficient space in the retromolar area can either prevent or delay the eruption of the third molars, while sufficient space, among other factors, can aid in their eruption. Multiple authors confirmed a positive correlation between a larger retromolar space and eruption of lower third molars (Svendsen and Bjork 1988; Ghougassian and Ghafari 2014). This also explains why in subjects with early physical maturation associated with limited growth of the mandible, there is a reduction in the size of the retromolar space which can lead to a higher risk of impaction (Bjork, Jensen, and Palling 1956). Indeed, Bjork et al. (1856) found that 90% of third molar impaction cases had reduced space distal to the lower second permanent molar (Bjork, Jensen, and Palling 1956). Another study also showed that a smaller retromolar space was significantly noticeable in the impacted group compared to the erupted one (Al-Gunaid et al. 2019), Zelic and Nedeljkovic (2013) concluded that regardless of age of the patient, the subgroup with adequate space had a higher rate of eruption of third molars when compared to the subgroup with lack of space (Zelic and Nedeljkovic 2013).

Notably, the ramus is considered to be an anatomic restriction for the space availability of the third molar eruption. This can contribute to the association between impaction and lower third molar crowding. This explains why investigators began to measure the distance between the mandibular terminal molar and the ramus. Basically, the retromolar space changes with growth of the anterior portion of the ramus and dimension of the mandible (Ghougassian and Ghafari 2014).

Ricketts et al. (1976) analyzed 25 skulls and 31 head films and confirmed that if 50% of the crown of the lower third molar is positioned mesial to the external ridge, it will have an approximately 50% chance of erupting. This also means that the further distal the lower third molar, the poorer the eruption prognosis becomes (Ricketts et al. 1976).

Many authors support the idea that the etiology of third molar impaction is multifactorial. For instance, in a longitudinal growth study using implants and cephalometric radiographs, Bjork (1963) found both skeletal and dental factors that were correlated with lower third molar impaction. The author mentioned that those factors can include shorter mandibular length, measured from the head of the condylion to pogonion, condylar growth that is more vertical as determined by the angle formed by the mandibular base and the ramus, late third molar maturation and lower dentition that is directed backward as indicated by the degree of alveolar inclination (Bjork 1963).

Behbehani et al. (2006) studied 134 patients and concluded that the available eruption space, forward rotation of the mandible during growth, and pronounced mesial angulation of the tooth buds contribute to a higher risk of impaction (Behbehani, Artun, and Thalib 2006). Richardson (1987) concluded that both resorption of the bone in the posterior aspect of the dental arch and anterior movement of the dentition contribute to the eruption space for third molars. When the resorption process is more significant at the posterior aspect of the mandible, the forward movement of the teeth is reduced. The most significant increase in space occurs when there is a greater amount of mandibular growth and when the dentition erupts anteriorly (Richardson 1987).

In brief, even if there are different beliefs when it comes to third molar impaction and eruption, most authors support its correlation with skeletal characteristics. One of the factors that is commonly shared is the link between impaction and more vertical condylar and facial growth. More severe angulation of the third molars can also contribute to impaction. Finally, the most commonly shared belief regarding the factors contributing to impactions is the insufficient eruption space in the posterior retromolar space. This issue may be due to the unfavorable distal eruption of the dentition or insufficient resorption of the anterior portion of the ramus (Almpani and Kolokitha 2015).

2.4 Growth and Development of the Retromolar Space

Growth of the mandible has been well-documented by scholars such as Enlow and Harris (Enlow and Harris 1964) and Bjork (Bjork 1963). Enlow and Harris (1964) described the patterns of remodeling and areas of relocation during growth of the mandible in younger subjects (Enlow and Harris 1964). The anterior border of the mandibular ramus undergoes resorption, drifting posteriorly, while the posterior border undergoes deposition. This occurs while growth at the condyle (in the direction of the mandibular fossa) lengthens the mandible and allows for downward and forward displacement. In their work, Enlow and Harris (1964) concluded that the ramal surface undergoes remarkable remodeling alterations which happen in conjunction with growth (Enlow and Harris 1964).

Other scholars have then looked more specifically at growth of the retromolar space (Ganss et al. 1993; Zelic and Nedeljkovic 2013; Chen et al. 2010; Ghougassian and Ghafari 2014). Ganss and colleagues (1993) found that the ratio between space present and third molar crown width was significantly increased in subjects between the ages of 16 and 20 with third molars erupted, while remained mostly constant (no growth) in the impacted teeth group.

2.4.1 **Remodeling and Growth of the Retromolar Space**

Richardson (1987) evaluated the retromolar space in the five years following the eruption of the permanent dentition anterior to the lower first permanent molars. From ages 13 to 18, the average total molar space increased by 4mm, the posterior molar space at the anterior border of the ramus increased by aprroximately 2mm, and the lower first permanent molar mesialized by approximately 2mm (Richardson 1987).

Chen et al. (2010) noted an increase in the retromolar space of 5.79mm and 5.12mm in males and females respectively and a resorption of 3.76mm in females and 5.77mm in males of the anterior region of the ramus for the same observational period. The main contributor to the increase in retromolar space was the resorption of the ramus since the mesialization of the dentition only occurred after the third molars erupted. The authors revealed that from age 13 to age 18, there was only very small variation in the width of the ramus, which means that the final width of the ramus has been attained before age 13. It is important to clarify that this does not imply that the remodeling of the ramus had stopped. Indeed, little variation in the width of the ramus should be interpreted as a result of an approximately equal amount of change between apposition at the anterior region of the ramus and backward resorption of the ramus (Chen et al. 2010). Ledyard (1953) found little variation in the width of the ramus after age 8 because the width remained constant as growth continued (Ledyard 1953). See TABLE V (Appendix) for a comparison between results of current study and prior literature with regards to the average increase of the retromolar space for different age points.

2.4.2 <u>**Age of Retromolar Space Growth Cessation**</u>

Some authors believe that the growth of the retromolar space does not continue after age 16 (Niedzielska et al. 2006; Ganss et al. 1993). On the other hand, Zelic and Nedeljkovic (2013) demonstrated that the width ratio of retromolar space to third molars was found to be different between subjects from 16 to 18 years old and those above 18 years old. The lack of space in the younger subjects' group was more frequent and the mean value of the width ratio between retromolar space and third molars was clearly reduced in the same group. The authors support that the size of the retromolar space cannot be predicted accurately at 16 years old because growth is still present and will eventually lead to an improvement of the retromolar space/third molar width ratio. This suggests that the decision regarding the extraction of third molars cannot be accurately made in early adulthood (Zelic and Nedeljkovic 2013). Chen et al. (2010 agrees with

Zelic and Nedeljkovic's (2013) study in that space insufficiency was seen more commonly in younger subjects in comparison to adults therefore, the retromolar space is still changing and growing even after 16 years of age. They argued that this change in dimension will be beneficial to the space to third molar dimension ratio (Chen et al. 2010).

Shiller's (1979) study agrees with Zelic and Nedeljkovic (2013) and Chen et al. (2010) that retromolar pad growth continues after age 16 and its cessation only occurs at an average age of 20 (Shiller 1979). Indeed, change in the lower third molars' position from a higher to a lower position in the ramus with forward movement of the roots that decreased the mesial inclination of the coronal aspect of the teeth and allowed their eruption, appeared to be associated with continuous growth of the mandible. This growth can be responsible for the increase in size of the retromolar space until age 20. Beyond that age, growth can be considered negligible, however some cases will continue to grow and that will create extra space for a favorable positioning of the third molars (Shiller 1979). However, Legovic et al. (2008) posited that having enough retromolar space for the third molar cannot be automatically considered as a predictor of normal or abnormal eruption. For these authors, the measurement of the posterior available space is still relevant as it can serve as a reference to predict impactions at around 18 years old when remodeling of the ramus is almost completed and when the third molars are about to erupt (Legovic et al. 2008).

2.4.3 **Sex Differences**

Confounding the analysis of posterior space is the potential for the growth of the mandible to affect the size of the dental arch (Ghougassian and Ghafari 2014). That growth is subject to individual variation and Proffit and Fields (2012) described an acceleration in the general growth of the body at puberty, which will also affect both the maxilla and mandible (Proffit and Fields 2012). On average, the growth curve of the lower jaw tends to follow the curve of the general body (height) more closely than the upper jaw. There is a growth spurt of mandibular length in adolescents, however is it not as significant in magnitude as body height. Even if growth of the mandible and maxilla tend to correlate with growth in height and in the physiologic changes of puberty, sometimes, especially among females, an acceleration of growth in the jaws can happen approximately 1 to 2 years before the growth spurt during adolescence. Indeed, a significant difference in the timing and velocity of height growth exists between females and males. On average, the growth spurt and puberty in females occur approximately 2 years sooner than in males, however males will have the tendency to grow larger in size and for a longer period of time (Proffit and Fields 2012). It is important to note that jaw size, facial growth and the size of the teeth will also differ among populations and races (Zelic and Nedeljkovic 2013).

Chen et al. (2010) highlighted differences specifically in the retromolar space development between sexes. The authors examined the changes of the retromolar space in 28 adolescents from 13 to 18 years old. An increase in space of 5.79mm and 5.12mm in males and females respectively was been found. Between 16 and 17 years of age, males had an increase in space of 1.20mm while females showed an increase of 1.3mm between 17 and 18 years old. These findings also confirmed that the third molar erupts later in males than in females. This study showed that mandibular ramus resorption was completed in females approximately 1 year before males. There was no measurable resorption in females after 16 years old or after 17 years old in males. Notably, the space increased 1.22mm (per side) each year in females before 16 years old and 1.45mm (per side) each year in males before 17 years old. It was concluded that age and sex should be considered when it comes to the prediction of the space in the posterior arch (Chen et al. 2010). This disagrees with Zelic and Nedeljkovic (2013), who found no difference between sexes in the width of the clinical third molar crown, gonial angle, retromolar space or eruption levels (Zelic and Nedeljkovic 2013).

Ghougassian and Ghafari's (2014) cross-sectional study looked at the relationship between the stage of formation of the third molars and the retromolar space and concluded that for the 96 orthodontic patients evaluated, only the retromolar space was considered statistically significantly different between sexes. The average age of all the males and females studied were 13.60 and 13.20 respectively. Females had an average retromolar space of 13.31mm and males had an average space of 13.01mm (Ghougassian and Ghafari 2014).

2.4.4 **Previous Research Design**

Only a few studies have looked specifically at the growth of the retromolar space, however most of them were either cross-sectional studies (Ghougassian and Ghafari 2014; Zelic and Nedeljkovic 2013) or studies with small sample sizes (Chen et al. 2010; Richardson 1987). Longitudinal studies allow a thorough evaluation of the potential patterns and trends that cannot normally be observed in a cross-sectional study(Richardson 1987; Chen et al. 2010; Ganss et al. 1993). Some used methods which included the analysis of two-dimensional lateral cephalometric images to evaluate growth, however those studies did not address the possible asymmetry between left and right structures (Ghougassian and Ghafari 2014; Chen et al. 2010; Richardson 1987). The superimposition of bilateral structures on a cephalometric radiograph increases the risk of method error and inaccuracy of the measurements (Houston 1983).

Some studies (Chen et al. 2010; Ghougassian and Ghafari 2014; Zelic and Nedeljkovic 2013) also evaluated the differences between males and females with regards to growth in the retromolar area, while Ganss (Ganss et al. 1993) and Richardson (Richardson 1987) did not highlight those differences. Unlike studies that focused on the effect of dental extractions on the eruption of lower third molars, Ghougassian and Ghafari (2014) focused their research on the effect of dental extractions on third molar formation (Ghougassian and Ghafari 2014). Moreover, Zelic and Nedeljkovic (2013) and Ganss et al. (2013) measured the ratio between the third molar crown and the retromolar space with regards to their predictability of eruption (Ganss et al. 1993; Zelic and Nedeljkovic 2013).

Our current study is different from previous research in that we were able to examine growth of the retromolar space in a larger, longitudinal dataset and examine the difference between sex and third molar classifications with regards to that space.

III. MATERIALS AND METHODS

3.1 **Subjects**

Our sample comprised de-identified lateral cephalometric radiographs of Caucasian individuals taken from three growth studies: Denver, Iowa and Oregon. These growth studies are publicly available from the American Association of Orthodontists Foundation Craniofacial Growth Legacy Collection. Radiographs were collected for all subjects at 5 ages (8, 10, 12, 14, and 18 years). The study was approved as exempt by the University of Illinois at Chicago's Institutional Review Board (protocol: 20191364).

The criteria for inclusion and exclusion in this study were as follows:

3.1.1 **Inclusion Criteria**

- Cephalometric radiographs of subjects taken at approximately 8,10,12,14 and, if available, at 18 years old (within 6 months of each age point)
- Cephalometric radiographs with clear and traceable structures
- Subjects with full dentition

3.1.2 **Exclusion Criteria**

- Subjects with an incomplete set of cephalometric radiographs (not including age 18), or radiographs taken at incorrect time points
- Subjects with history of orthodontic treatment or dental extractions

- Cephalometric radiographs with compromised quality or distortion of the image
- Subjects with congenitally missing teeth

A total of 99 out of 301 subjects, which included 56 males and 43 females remained following the application of the exclusion criteria (25 subjects from Denver, 35 subjects from Iowa and 39 subjects from Oregon). Cephalometric radiographs with presence of lower third molars were evaluated at age 18 for a total of 41 subjects, which included 24 females and 17 males. Subjects were classified by sex, age and angle classification.

3.2 Digital Landmark Identification

Six landmarks were identified on each subject's lateral cephalometric radiograph (Figure 1). These landmarks were used to evaluate the growth changes of the retromolar space. The digital landmarking was completed using Dolphin Imaging™ software (Version 11.95 Premium Dolphin Imaging Systems LLC, Chatsworth, LA). The landmarking of each subject's lateral cephalometric radiograph was completed by a single investigator (ANN). For the bilateral landmarks, a midpoint was used. Intra-rater reliability testing was performed by re-tracing five subjects from each growth study four weeks after the first tracing.

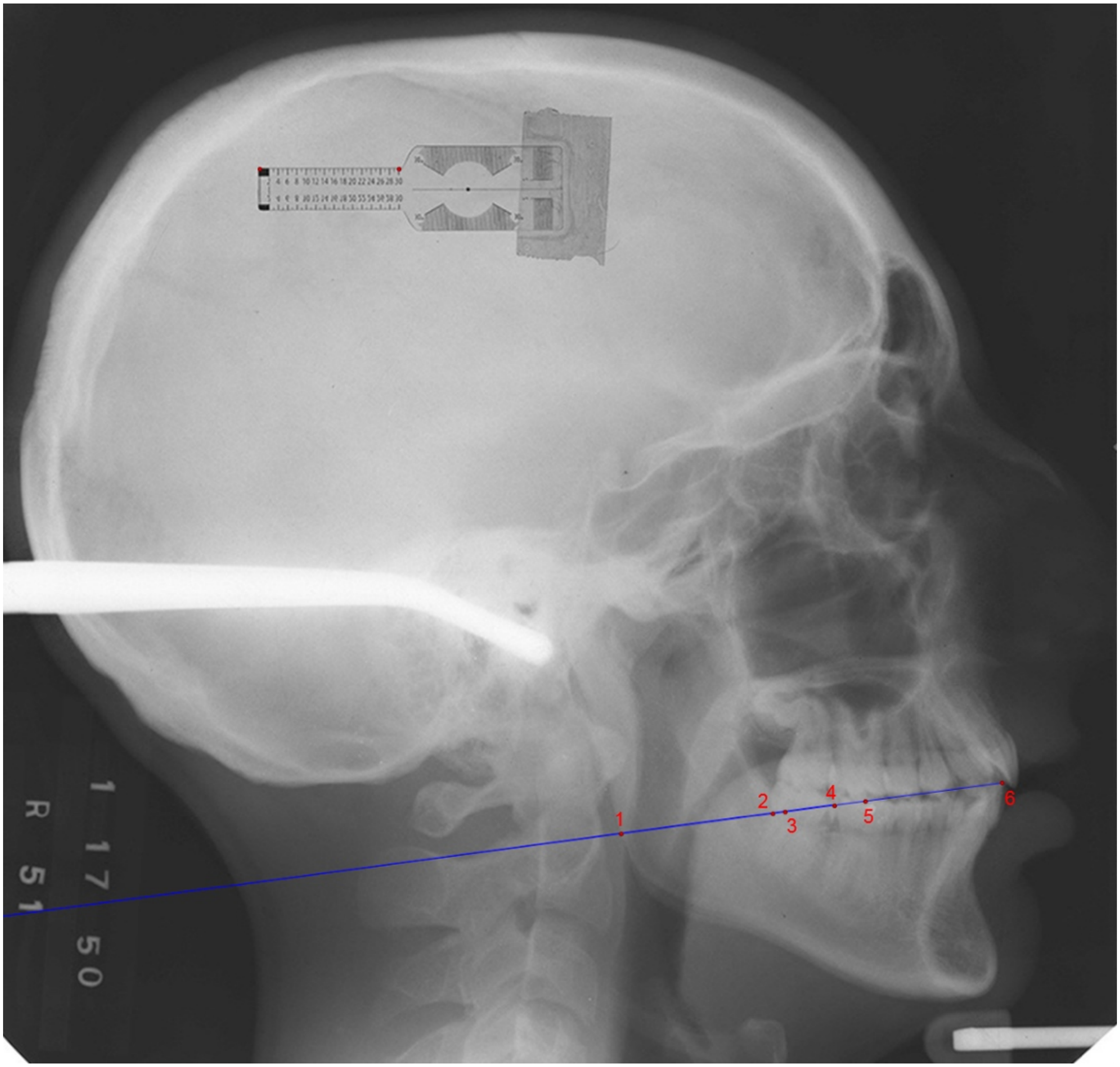


Figure 1: Example of a lateral cephalometric radiograph with identified digital landmarks: 1, the posterior border of the ramus; 2, the distance between the distal of the lower 2nd permanent molar to the anterior border of the ramus; 3, the anterior border of the ramus; 4, the distance between the distal of the lower 1st permanent molar to the anterior border of the ramus; 5, the occlusal of the lower 1st permanent molar; 6, the lower central incisor tip.

3.2.1 **Selected landmarks**

The mandibular occlusal plane was established as a line connecting the incisal edge of the lower incisor and the occlusal surface of the 1st molar (Gilmore 1950). The longitudinal assessment of growth of the retromolar space was completed using the following points along the mandibular occlusal plane:

1. Posterior border of the ramus
2. Distance between the distal of the lower 2nd permanent molar to the anterior border of the ramus
3. Anterior border of the ramus
4. Distance between the distal of the lower 1st permanent molar to the anterior border of the ramus
5. Occlusal of lower 1st permanent molar
6. Lower central incisor tip

3.2.2 **Measurements**

The following measurements were registered by evaluating the distance between the selected landmarks:

- Width of the ramus using the mandibular occlusal plane (Point 1 to Point 2)
- For 8,10 and 12-year-old subjects - Distal of lower 1st permanent molar to the anterior border of the ramus using the mandibular occlusal plane (Point 3 to Point 4)
- For 14 and 18-year-old subjects - Distal of 2nd molar to the anterior border of the ramus using the mandibular occlusal plane (Point 2 to Point 3)

- For all subjects: Lower central incisal tip to anterior border of the ramus using the mandibular occlusal plane (Point 3 to Point 6)

3.3 Pell and Gregory Classification of Molar Impaction

Cephalograms from subjects at the approximately 18 year old time point with developing lower third molars were classified using the Pell and Gregory classification system, an established method for evaluating the level of difficulty of third molar extraction (Figure 2) (Pell and Gregory 1933). A total of 41 subjects which included 24 females and 17 males were evaluated. The teeth were evaluated based on the overlap between the anterior border of the ramus and the third molar (Classification I, II or III) (Pell and Gregory 1933). This classification system is defined as:

- Class I: Adequate space between distal surface of the lower second permanent molar and the ramus to accommodate the crown of the lower third molar.
- Class II: Inadequate space between distal surface of the lower second permanent molar and the ramus to accommodate the crown of the lower third molar.
- Class III: Most or all of the lower third molar crown is in the ramus.

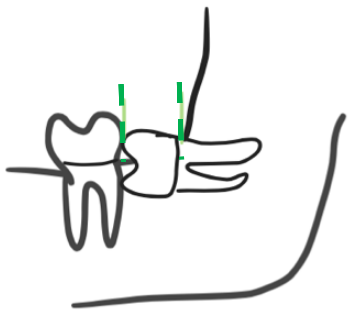
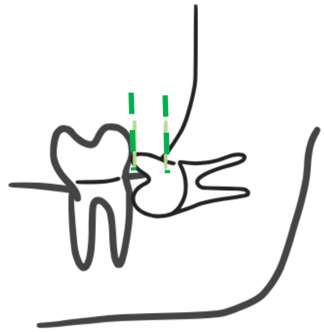
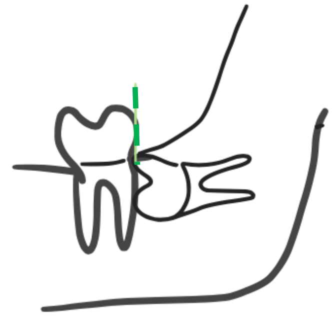
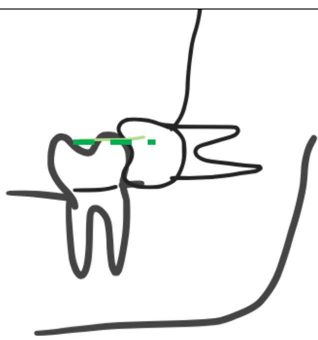
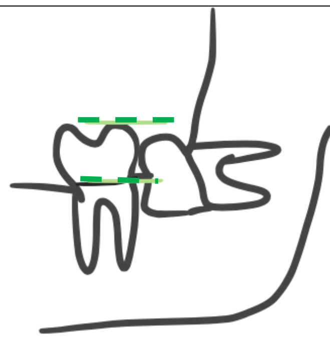
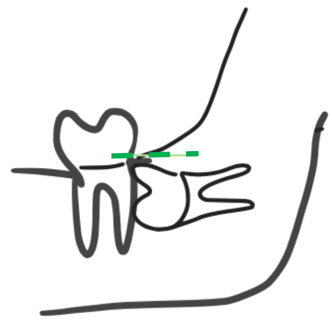
Class I	Class II	Class III
		
Position A	Position B	Position C
		

Figure 2: The Pell and Gregory (1933) classification system. Class I, adequate space between distal surface of the 2nd molar and the ramus to accommodate the 3rd molar; Class II, inadequate space between distal surface of the 2nd molar and the ramus to accommodate the 3rd molar; Cl III, most or all of the 3rd molar is in the ramus. Position A, highest point of the 3rd molar crown is either above or on the same level as the occlusal plane of the 2nd molar; Position B, highest point of the 3rd molar crown is below the occlusal, but above the cervical of the 2nd molar; Position C, highest point of the 3rd molar is below the cervical of the 2nd molar.

This classification also takes into consideration the depth of the impaction in relation to the lower second molar and defines it as Position A, B, or C (Pell and Gregory 1933).

- Position A: Highest point of the lower third molar crown is either above or on the same level as the occlusal plane of the lower second permanent molar.
- Position B: Highest point of the lower third molar crown is below the occlusal plane, but above the cervical delimitation of the lower second permanent molar.
- Position C: Highest point of the lower third molar crown is below the cervical delimitation of the lower second permanent molar.

3.4 **Statistical Methods**

A series of Shapiro-Wilks tests were conducted to test for normality of the data followed by Bartlett's tests for homogeneity. Much of the data was non-normally distributed and/or the data was not homogenous, so where appropriate, non-parametric tests were run.

Initial analyses included descriptive statistics as well as a series of Kruskal-Wallis and Analysis of Variance (ANOVA) tests to examine whether there were baseline differences between our three datasets (Denver, Iowa, Oregon).

T-tests (for the normally distributed data) and Wilcoxon Rank Sum tests (for the non-normally distributed data) were conducted to compare retromolar space (in mm) between males and females at each age point. These tests were also used to compare the amount of change in retromolar space (Age 8 – 10, Age 8 – 12, Age 8 -14, Age 8 -18) across sexes. To assess change in retromolar space through time across sexes, we employed a repeated measures ANOVA and a fixed effects model.

To assess the association between third molar classification and retromolar space, we ran a series of ANOVA/Kruskal-Wallis tests at different age points. To examine longitudinal trends by third molar classification, we ran a repeated measures ANOVA.

IV. RESULTS

4.1 Statistical Analysis of Growth

Our descriptive statistics reveal that at Age 8, the average retromolar space was 3.27mm (3.42mm for females, 3.17mm for males). By Age 14, the oldest age for which we had data for all subjects, the average space was 10.22mm (9.89mm for females, 10.5mm for males). For our subsample that included age 18, the average retromolar space was 11.92mm (11.49mm for females, 12.45 for males) (TABLE I). Variability within in the sample in terms of pattern of growth can be seen in the spaghetti plot below (Figure 3).

TABLE I
AVERAGE RETROMOLAR SPACE (IN MM) ACROSS GROWTH (STANDARD DEVIATION IN PARENTHESES)

	8 yr	10 yr	12 yr	14 yr	18 yr	8 – 10 change in mm	8 – 12 change in mm	8-14 change in mm	8 – 18 change in mm
Males (N=56)	3.17 (2.27)	4.6 (2.40)	6.85 (3.22)	10.50 (3.48)	12.45 (2.65)	+1.43 (1.50)	+3.68 (2.01)	+7.33 (2.58)	+9.15 (1.96)
Females (N=43)	3.42 (1.66)	4.84 (2.30)	7.45 (2.73)	9.87 (2.25)	11.49 (1.59)	+1.42 (1.34)	+4.03 (2.01)	+6.45 (1.83)	+8.41 (1.36)
Combined sample	3.27 (2.01)	4.70 (2.34)	7.11 (3.02)	10.22 (3.01)	11.92 (2.15)	+1.43 (1.42)	+3.84 (2.01)	+6.95 (2.32)	+8.74 (1.67)

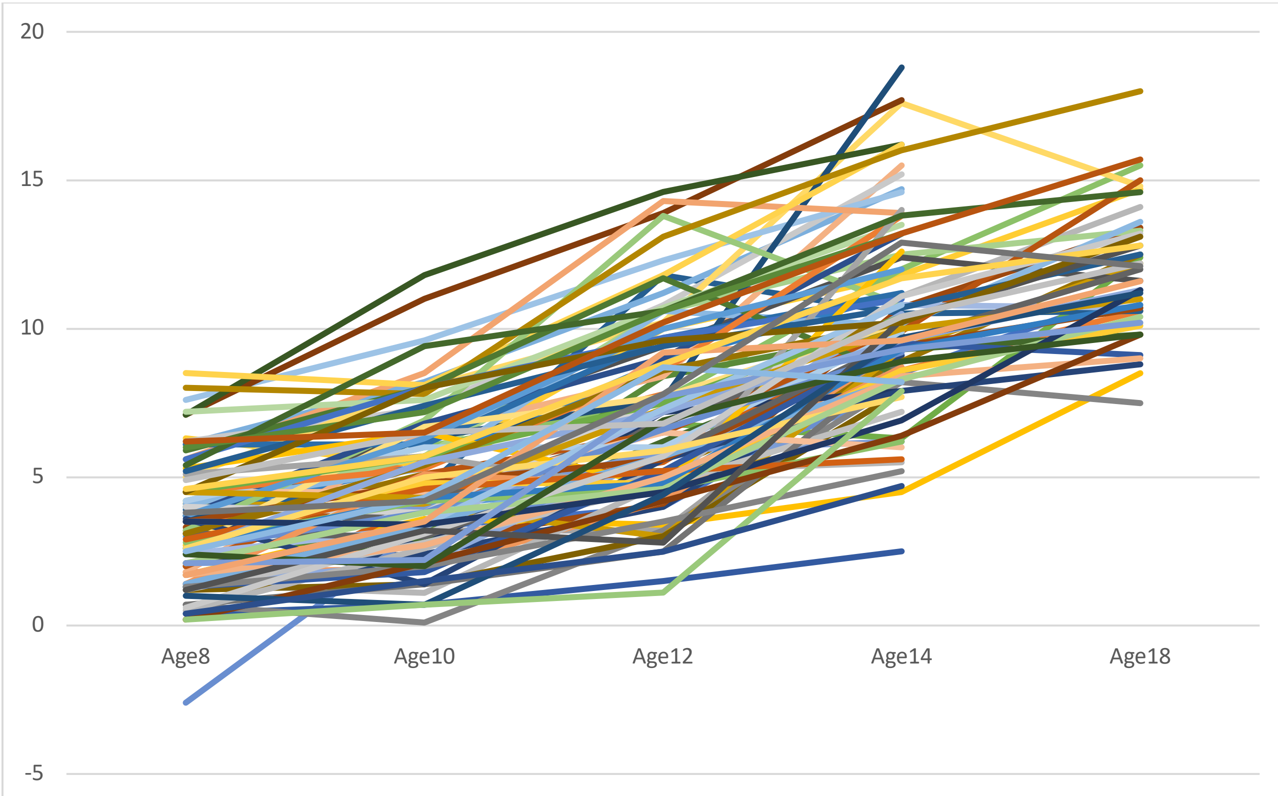


Figure 3. Spaghetti plot depicting variability in retromolar space growth in the sex-combined sample.

Initial examination of the data included a series of Kruskal-Wallis and ANOVA tests comparing the mean measurements across the three samples (Iowa, Denver, Oregon). There were found to be statistically significant differences (p=0.049 – p<0.001) and Tukey-HSD tests revealed that Iowa was statistically dissimilar from Denver and Oregon (p<0.001) for all age points except Age 18 (Iowa – Oregon p=0.02; Iowa – Denver p=0.08). However, upon examination of the dataset with and without the Iowa sample, there were no differences in overall outcomes, such as the pattern of retromolar space growth between sexes. It appears that the Iowa sample measurements were somewhat larger on average (e.g., at Age 8, the mean retromolar space was 4.49mm for Iowa and 2.61mm for the non-Iowa sample). However, given that this difference was statistically significant but did not appear to affect the outcome of comparisons between males and females, we ran our further analyses including the Iowa dataset. See TABLE II for the descriptive statistics without the Iowa sample.

TABLE II
AVERAGE RETROMOLAR SPACE (IN MM), EXCLUDING THE IOWA SAMPLE

	8 yr	10 yr	12 yr	14 yr	18 yr	8 – 10 change in mm	8 – 12 change in mm	8-14 change in mm	8 – 18 change in mm
Males	2.34 (1.92)	3.59 (1.83)	5.70 (2.61)	9.05 (2.52)	11.93 (2.39)	+1.25 (1.46)	+3.36 (1.88)	+6.71 (2.12)	+9.05 (2.11)
Females	2.98 (1.34)	4.30 (2.00)	6.69 (2.06)	9.44 (1.86)	11.26 (1.45)	+1.31 (1.21)	+3.71 (1.55)	+6.46 (1.56)	+8.17 (1.01)
Combined sample	2.61 (1.72)	3.89 (1.92)	6.12 (2.42)	9.21 (2.26)	11.56 (1.93)	+1.28 (1.36)	+3.51 (1.74)	+6.60 (1.90)	+8.56 (1.64)

Given that the both the absolute growth of the retromolar space (in mm) and the relative growth of the retromolar space (as a percentage of change) might be important for application in clinical practice, we also calculated descriptive statistics based upon the percent change in retromolar space from one age point to another (TABLE III). For example, we took the retromolar space (in mm) at Age 8 and subtracted it from retromolar space Age 10, and then divided the resultant amount by the retromolar space at Age 8.

TABLE III
PERCENTAGE OF CHANGE IN RETROMOLAR SPACE DISTANCE THROUGH TIME. AVERAGE CHANGE AND STANDARD DEVIATIONS

	8-10 Years Average % Change (SD)	8-12 Years Average % Change (SD)	8-14 Years Average % Change (SD)	8-18 Years Average % Change (SD)
Females	67% (145%) n=43	185% (299%) n=43	311% (468%) n=43	504% (917%) n=25
Males	102% (280%) n=56	215% (382%) n=56	491% (852%) n=56	472% (475%) n=20
Total	87% (231%) n=99	202% (347%) n=99	412% (714%) n=99	490% (746%) n=45

A series of t-tests (and Wilcoxon rank sum tests) revealed no statistically significant difference between retromolar space in males and females at any age. Nor did we see a difference in the change in retromolar space across sexes (e.g., the change in mm distance from 8 to 18); this held true when the Iowa sample was excluded from the dataset.

However, when we ran a repeated measures ANOVA and linear fixed effects model comparing variation in retromolar space size through time between males and females, there is a statistically significant difference in pattern ($p<0.001$). As can be seen in Figure 4, males and females show a similar overall trend in growth; however, females have larger retromolar spaces through Age 12, but at the Age 14 timepoint, males overtake females and show greater magnitude of growth going forward.

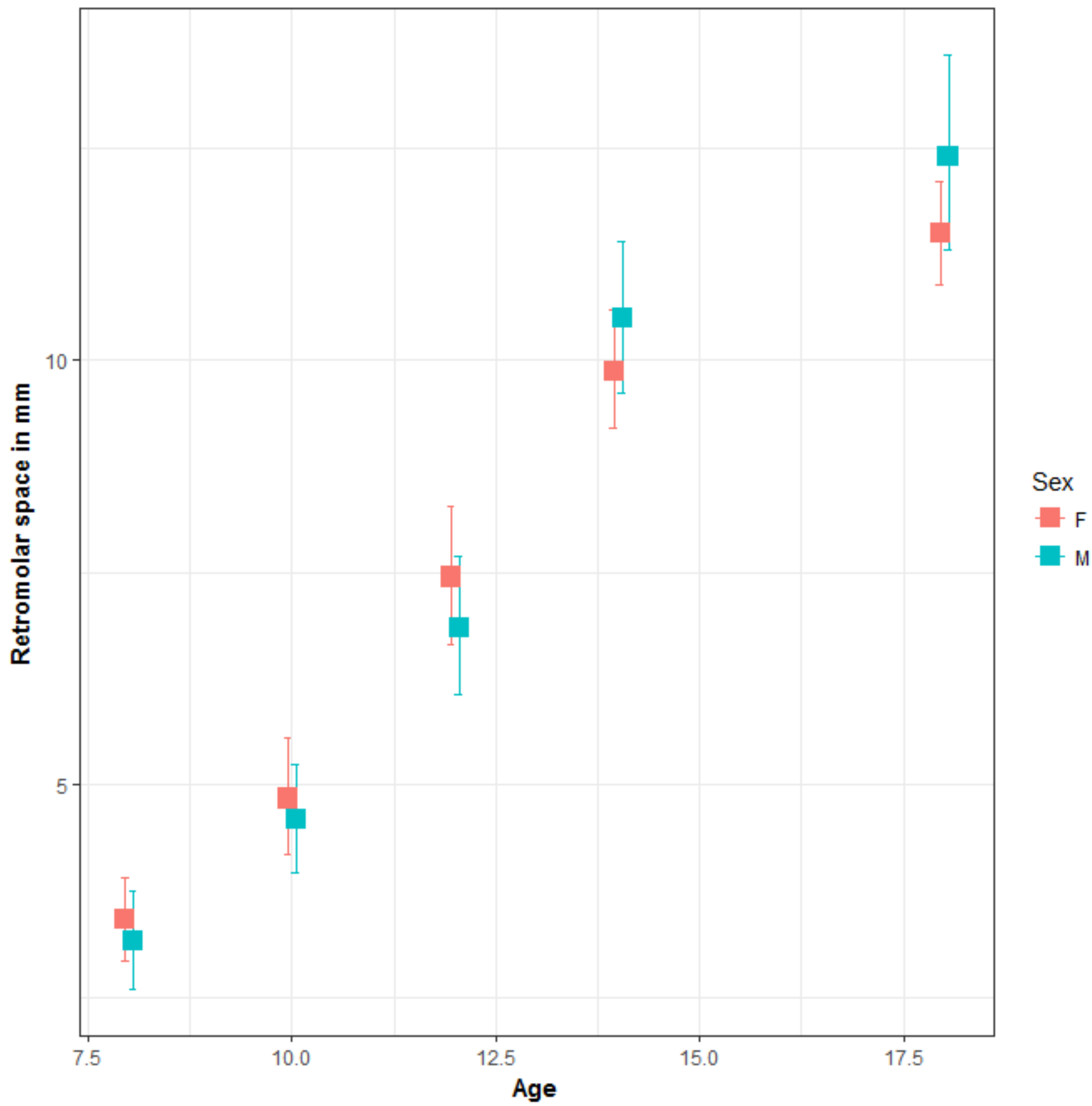


Figure 4. Linear fixed effects model comparing the variation in retromolar space (in mm) through time in males and females. There are differences between the male and female patterns ($p<0.001$). Males have a large increase in the magnitude of growth between ages 12-18.

4.2 **Statistical Analysis of Third Molar Classification**

Because third molar impaction is one of the key reasons why clinicians would wish to have a better understanding of the growth of the retromolar space, we compared third molar classifications (which indicate degree of impaction)(Pell and Gregory 1933). There were two or fewer subjects in third molar classification categories 1C, 2A, 2C, and 3C (TABLE IV), so these individuals were excluded from analyses of the relationship between retromolar space and third molar categorization.

TABLE IV

DISTRIBUTION OF SUBJECTS IN EACH MOLAR CLASSIFICATION

	Class I	Class II	Class III
Position A	9	2	
Position B	10	13	4
Position C	1	1	1

A series of Kruskal-Wallis tests were run to compare retromolar space at each age across the molar classification categories. No statistically significant differences were found. A repeated measures ANOVA also failed to find a relationship between third molar classification and retromolar space across time. When we look at the data (see Figure 5), we can see a general trend whereby individuals with Class 1A third molars tend to consistently have larger retromolar spaces, while those with Class 2B and Class 3B third molars tend to have somewhat smaller retromolar spaces.

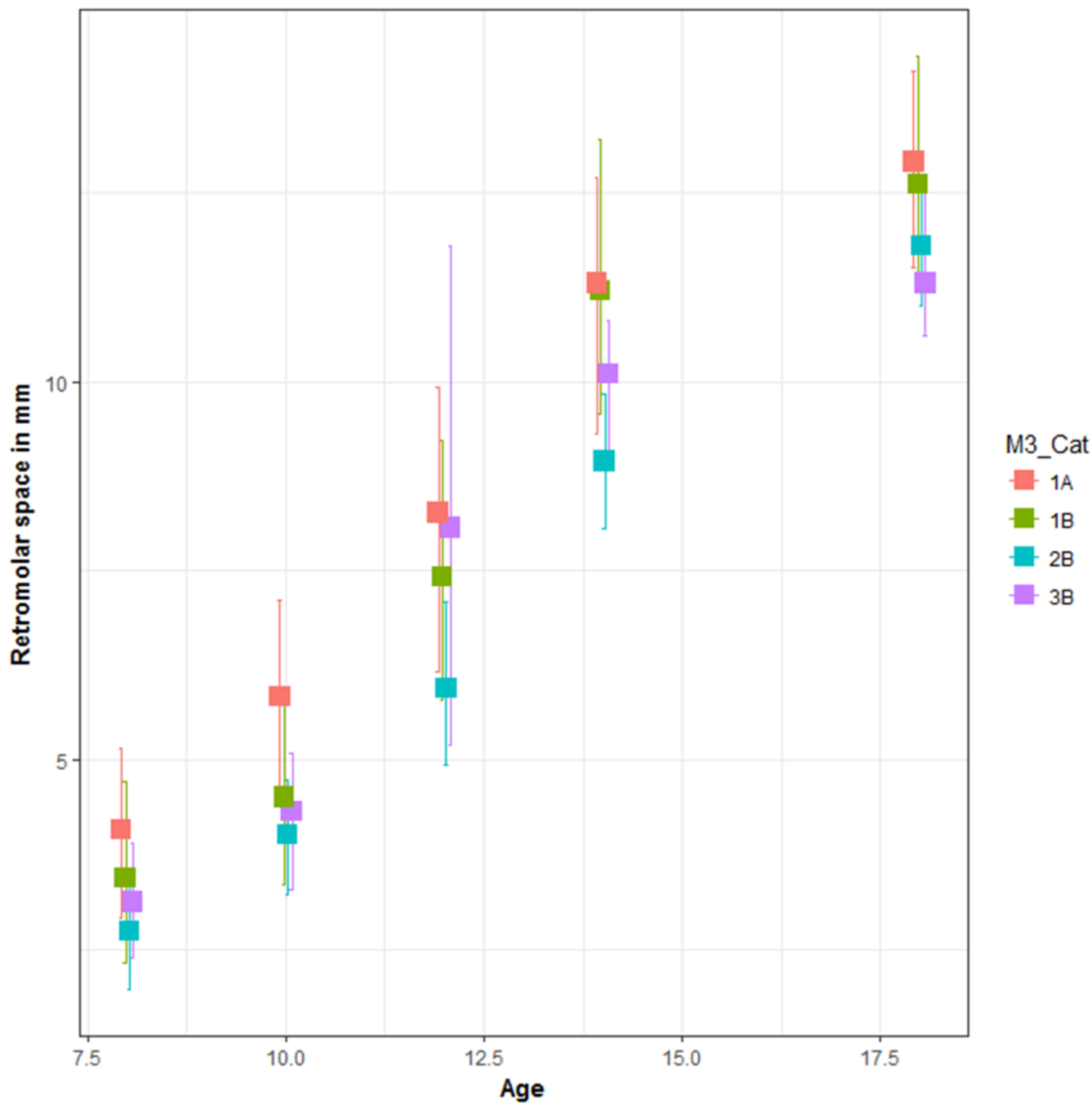


Figure 5. Boxplots depicting the longitudinal relationship between third molar classification and retromolar space (in mm). There is a general trend towards larger retromolar spaces in subjects with Class 1A third molars and smaller retromolar spaces in subjects with Class 2B and Class 3B third molars, but this difference is not statistically significant (p=0.132) nor is the interaction between third molar category and age (p=0.709).

V. DISCUSSION

5.1 Radiographic Images as Measuring Tools

Predictability of third molar eruption or impaction is clinically important (Zelic and Nedeljkovic 2013). The analysis of the retromolar space for adequate space management is important especially if this information can be used to aide in treatment planning for proper timing or necessity of tooth removal or maintenance. It is clinically relevant to be able to predict if there will be enough space for the lower third molars early on, in addition to aiding in decisions about extraction of other teeth (such as premolars) in cases of severe crowding (Al Kuwari et al. 2013; Brezulier, Fau, and Sorel 2017).

Lateral cephalometric radiographs were analyzed in our longitudinal retrospective study. Most previous studies on the retromolar space have also used this type of radiographs, which provides us with an appropriate basis for comparing the results. The retromolar space was measured from the distal surface of the lower terminal molar, either a lower second or a first permanent molar, to the anterior border of the ramus, based upon the methods used by Chen et al. (Chen et al. 2010) and Ganss et al. (Ganss et al. 1993), described below.

Chen et al. (2010 argue that measuring the retromolar space along the plane of occlusion is relevant for evaluating the probability of impaction or eruption of the third molars. The rationale is that an angle formed by the occlusal plane and corpus axis is a limitation in its predictive use clinically (Chen et al. 2010). Even though some research has suggested that the plane of occlusion tends to tilt during development, it was shown by the same authors that there was insignificant changes in the occlusal plane for teenagers from 13 to 18 years old. It is important to note that some factors can impact the vertical direction such as eruption of the dentition, rotation of the mandible or growth of the ramus vertically, however our measurements were taken in the anteroposterior dimension, which results in less influence. The linear measurements taken in our study were taken along the mandibular occlusal plane, in accordance with Chen et al. (2010), and they were also selected due to the proximity of the analyzed area, which is the retromolar space.

5.2 **Amount and Predictability of Growth**

Richardson (1987) evaluated the retromolar space in the five years following the eruption of the permanent dentition anterior to the lower first permanent molars. From age 13 to 18, the average total molar space increased by 4mm (Richardson 1987). Chen et al. (2010), for the same observational period, showed an increase in the retromolar space of 5.79 mm and 5.12mm in males and females respectively. In our current study, from 8 to 18 years, a total increase of 8.56mm (9.05mm in males, 8.17mm in females) of retromolar space was measured, which is not entirely unexpected since the observational period is longer in our study (10 years for our current study compared to 5 years for Richardson (1987)). Ghougassian and Ghafari (2014)'s cross-sectional study found statistically significant correlations between retromolar space and the age of subjects (Ghougassian and Ghafari 2014). The posterior available space was larger as the subjects aged, which was also shown in our results.

In terms of absolute dimensions, Chen et al. (2010) found that the average retromolar space increased from 15.79mm (males) and 16.15mm (females) at age 14 to 19.36mm (males) and 20.07mm (females) at age 18 (Chen et al. 2010). In our current study, average retromolar space increased from 3.17mm (males) and 3.42mm (females) at age 8, to 10.50mm (males) and 9.87mm (females) at age 14 and to 12.45mm (males) and 11.49mm at age 18. Our averages are smaller than those reported by Chen et al (2010).

Our current study shows that retromolar pad space increased by 6.95mm (412%) between age 8 and 14. From age 8 to 18, the retromolar pad space increased by 8.74mm (490%) which agrees with Ledyard's (1953) investigation, which observed significant growth between age 8 and 14, followed by reduced magnitude of growth after that age (Ledyard 1953). Ledyard (1953) showed that from the lower first molar to the anterior border of the ramus, there was an increase of 7.7mm from age 8 to 14. Between age 14 and 16-20 years old, 2.3 mm of growth was noted. It was concluded that at age 15 to 16, further growth of the area can be considered negligible (Ledyard 1953). Our study showed a change in the retromolar space from 10.22mm at age 14 to 11.92 at age 18, which is in agreement with Ledyard (1953).

Niedzielska et al. (2006) confirmed the observation that the retromolar space continues to grow until age 16 and concluded that in young adults, impaction and eruption after age 16 can be accurately predicted (Niedzielska et al. 2006). This is contrary to Zelic and Nedeljkovic (2013), who found an annual increase in the retromolar area for males between age 16 and age 17 (average 1.20mm) and for females between age 17 and age 18 (1.32mm) (Zelic and Nedeljkovic

2013). This increase was meaningful and the author concluded that the final size of the retromolar pad area cannot be accurately predicted in the age of 16 (Zelic and Nedeljkovic 2013).

5.3 **Growth Trends Between Sexes**

Our data indicates that while males and females have relatively similar raw measurements, the trend of growth is slightly different. As expected, females show more growth earlier but a younger age of growth cessation. There are differences between the male and female patterns, such that males show a pattern whereby they have a large increase in the magnitude of growth between ages 12-18. While in absolute numerical terms, our results tend to show smaller retromolar space values for females, our study shows no statistically significant difference between the retromolar space in males and females at any age. This is in contrast to Chen et al. (2010), who found a significant difference of the retromolar space between sexes. In this study, the space increased approximately 1.22mm in females before age 16 compared to 1.45 mm in males before age 17 on each side per year, which they found to be statistically significant. They concluded that the prediction of the available space should be based on sexes. This disagrees with Zelic who found no significant difference between sexes when the width of the clinical third molar crown, gonial angle, retromolar space and eruption levels were measured (Zelic and Nedeljkovic 2013).

Our longitudinal results show that females have larger retromolar spaces through age 12, but at the Age 14 time point both sexes begin to diverge, with males showing a larger magnitude of growth going forward. This is slightly different from Chen et al. (2010) who found that from age 13 to 18, the retromolar space in males was smaller than in females until age 17 time point, but the increase of the posterior space in males before age 17 was larger in magnitude than that in females. The authors explain that this is expected since males generally have more growth remaining than females at age 17. This was also in agreement with the general consensus that males reach maturity and will have their puberty and growth spurt about 1 to 2 years after females (Chen et al. 2010; Proffit and Fields 2012; Palmert and Boepple 2001).

Ghougassian and Ghafari (2014) revealed that the most significant increase of the retromolar space was between ages 10 and 12 and associated this change to the timing of the growth spurt (Ghougassian and Ghafari 2014). The authors also looked at the relationship between the stage of formation of the third molars and the retromolar space and concluded that for the 96 orthodontic patients evaluated, the retromolar space was considered statistically significantly different between sexes. The average age of all the males and females studied were 13.60 and 13.20 respectively (subjects ranged from 8 to 18 years old). Females had an average retromolar space of 13.31mm and males had an average space of 13.01mm (Ghougassian and Ghafari 2014). In our current study, subjects with an average age of 12 and 14 were found to have an average retromolar space of 7.11mm (6.85mm in males, 7.45mm in females) and 10.22mm (10.50mm in males, 9.87 in females) respectively which are overall smaller average measurements to those reported by Ghougassian and Gharafi's (2014) work.

5.4 **Lower Third Molar Position at Age 18**

Using the Pell and Gregory molar classification (Pell and Gregory 1933), our research revealed a general trend for individuals with Class 1A third molars to consistently have larger retromolar spaces, while those with Class 2B and Class 3B third molars tend to have somewhat smaller retromolar spaces. However, this difference is not statistically significant nor is the relationship between third molar category and age.

A similar trend was noted by Zelic and Nedeljkovic (2013) who found that in the subjects in the early adult group (younger group), the highest number of mandibular third molars was found to be in the C-position. Conversely, for cases where the third molars had enough space for eruption, the A-position was more often seen. In the older adult group, the highest number of the mandibular third molars were found in the A-position which is an indication of their future eruption (Zelic and Nedeljkovic 2013). Zelic and Nedeljkovic (2013) support the idea that lack of space in early adult subjects occurred more often than in older adults. The study revealed that the posterior available space does increase significantly after age 16, which will improve the chance of having enough space for eruption of third molars. This supports the argument that decision for tooth extraction should be made at a later age (Zelic and Nedeljkovic 2013).

Furthermore, Jain et al. (2019) found that, out of 357 subjects over age 18, the most common type of angulation for impacted third molars was mesioangular (39%). About 60.65% of the impactions were seen in subjects with Class II malocclusions and the most frequent level of impaction based on the Pell and Gregory classification was found to be B (Jain, Debbarma, and

Prasad 2019). Our current study also revealed that some third molars at age 18 are classified as B.

5.5 <u>**Limitations**</u>

Our study has some limitations that are unavoidable in a retrospective study. We were limited by the availability of radiographic images and many subjects did not have radiographs at all the time points we evaluated. Those subjects with missing cephalometric radiographs had to be excluded from the study, reducing our sample size.

Another limitation is that the specific width of the third molars has not been measured, therefore the relationship between the space available and the diameter of the crown has not been established in our study. Even if data on the relationship between the size of the clinical crown and impaction is still lacking (Ghougassian and Ghafari 2014), this information could have been interesting to have considering that the ratio between crown width and available retromolar space is one of the possible predictors of third molar impactions as mentioned by some authors (Ganss et al. 1993). Additionally, the sample size for the subjects with presence of third molars is somewhat small.

As mentioned earlier, the use of two-dimensional cephalometry is confounded by the superimposition of the anatomical structures creating double images of the right and left sides in projection. This inevitably reduces the accuracy and increases the level of difficulty when identifying the desired landmarks.

Another limitation encountered in our study is the fact that the subjects were not classified by type of malocclusions. A close relationship exists between dental and skeletal development and as mentioned earlier, the retromolar space might be different based on the type of malocclusions which may also affect the eruption and maturation of the teeth (Ghougassian and Ghafari 2014).

A last limitation is that our study included only a Caucasian population, and therefore is not diverse in terms of ethnicity and race. Our results are not predictive values that can necessarily be applied to a general population, however the general principle of growth and development can be comparable.

5.6 **Recommendations for Future Studies**

Ours findings add to the body of literature establishing the typical amount of retromolar space growth to be expected at a given age. For further research, it would be interesting to consider a possible use of a more modern method using three-dimensional images such as cone beam computed tomography (CBCT) for more accuracy. From a clinical standpoint, it would also be interesting to look into the potential prediction of the posterior available space and the measurement of mandibular second molar crowns in growing patients. A last recommendation for future studies involve the evaluation of the growth of the retromolar space based on cervical vertebral maturation and age of menstruation. The onset of menarche is considered to be a good indicator of sexual maturity, which is accompanied by growth spurt (Proffit and Fields 2012).

VI. CONCLUSION

Our results failed to provide clear support for previous work, which has shown differences in the trend of growth of the retromolar space between males and females. Specifically, at no age point do we find statistically significant differences in retromolar space in either absolute measurements or percentage of change. However, we do document a trend whereby females show earlier growth and a younger cessation of growth.

We also failed to find a statistically significant relationship between third molar stage and retromolar space. We did, however, observe a general trend whereby individuals with Class 1A third molars tend to consistently have larger retromolar spaces, while those with Class 2B and Class 3B third molars tend to have smaller retromolar spaces. Future studies with larger sample sizes at our final time-point (age 18) might help to clarify this relationship.

APPENDIX

TABLE V
COMPARISON BETWEEN RESULTS OF CURRENT STUDY AND PRIOR LITERATURE WITH REGARDS TO THE AVERAGE INCREASE OF THE RETROMOLAR SPACE FOR DIFFERENT AGE POINTS

Study	8 - 14 years	12/13 - 18 years
Chen et al. (2010)*	-	5.79mm males/5.12mm females
Richardson et al. (1987)*	-	4mm
Ledyard (1953)	7.7mm	-
Current study **	6.95mm	5.02mm 5.84mm males/4.38mm females

*13-18, **12-18

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