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AGENESIS OF MAXILLARY LATERAL INCISORS IN ORTHODONTIC
PATIENTS AND THE RELATION TO OVERALL TOOTH SIZE

by

Jane Wright, DDS

A Thesis submitted to the Faculty of the Graduate School,
Marquette University,
in Partial Fulfillment of the Requirements for
the Degree of Master of Science

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ABSTRACT
AGENESIS OF MAXILLARY LATERAL INCISORS IN ORTHODONTIC
PATIENTS AND THE RELATION TO OVERALL TOOTH SIZE

Jane Wright, DDS

Marquette University, May 2011

The maxillary lateral incisor is the second most frequently missing tooth in the dental arch with clinical management requiring a complex and multidisciplinary treatment approach. It has been suspected that teeth could be smaller in the maxillary or mandibular arches in patients experiencing agenesis of the maxillary lateral incisor, making ideal occlusal relationships and space creation for restoration of the lateral incisor difficult to obtain. The purpose of this study is to determine if a tooth size discrepancy exists in orthodontic patients with agenesis of the maxillary lateral incisor(s).

Forty sets of dental casts from Caucasian orthodontic patients (19 male and 21 female) mean age 15.9 years were gathered from orthodontists in the Greater Milwaukee area. All casts had agenesis of one or both maxillary lateral incisors but an otherwise full complement of teeth from first molar to first molar. The teeth were measured with a digital caliper at their greatest mesio-distal width and then compared to a control group gathered from Marquette University's Orthodontic department matched for ethnicity, age and gender.

Males in the test group had significantly smaller maxillary posterior teeth when compared to males in the control group, with differences in posterior tooth size ranging from 0.28-0.78mm. Females in the test group showed significantly smaller maxillary anterior teeth with significant differences ranging from 0.22-0.42mm. The posterior teeth (first bicuspid through first molar), were not significantly smaller in the female test group. Some of the test group's mandibular teeth for males and females were smaller than normal, but no apparent pattern was observed. The remaining maxillary lateral incisor was also significantly smaller (1.27mm difference) in the male and female unilateral agenesis test groups indicating higher incidence of 'peg' laterals when compared to the control group.

The present study found that agenesis of one or both maxillary lateral incisors is associated with a tooth size discrepancy. Caucasian males experienced smaller than normal posterior maxillary teeth and females showed smaller anterior maxillary teeth. It is important for clinicians to recognize a tooth size discrepancy before creating a treatment plan for a patient experiencing a missing maxillary lateral incisor.

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Jane Wright, DDS

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	i
CHAPTER	
I. INTRODUCTION.....	1
Purpose.....	2
Hypothesis.....	2
II. REVIEW OF THE LITERATURE.....	3
Agenesis of the Maxillary Lateral Incisor.....	3
Restorative Considerations with Agenesis.....	4
Genetics, Tooth Size and Associated Anomalies.....	6
Gender and Ethnicity.....	11
Malocclusion and Tooth Size.....	12
Agenesis and Tooth Size.....	16
III. MATERIALS AND METHODS.....	20
IV. RESULTS.....	24
V. DISCUSSION.....	31
VI. CONCLUSION.....	36
BIBLIOGRAPHY.....	38
APPENDIX A.....	43

CHAPTER I

INTRODUCTION

Orthodontists often experience problems related to the management of clinical conditions when patients are congenitally missing a maxillary lateral incisor. Some treatment options for missing lateral incisors are: an implant and crown, a fixed partial denture or moving the canine forward to substitute for the missing lateral incisor. It can be difficult determining the optimal amount of space required for ideal restoration of the missing maxillary lateral incisor. The opposite lateral incisor can be measured and used as a reference for the missing lateral incisor¹, however, in cases of agenesis the remaining lateral incisor is frequently peg shaped or missing as well.² Another approach to determine the appropriate size for the lateral incisor is to use the 'Golden Proportion' in which case the lateral incisor should be about 2/3rds the width of the central incisor.³ Kokich advocates using the Bolton Analysis⁴ to determine the required space for the missing lateral incisor.¹

Once a clinician has determined the amount of space necessary to restore the lateral incisor(s), maintaining class I canines and proper overbite and overjet relationships while creating enough room for an implant can be problematic. A minimum of 6mm, but ideally 7mm of space, is recommended for an implant in the area of the lateral incisor.^{5,6} Yet, in many clinical situations, when the midlines are coincident, canines are in a class I relationship and ideal overbite and overjet are established, clinicians may still lack the required space. Because of this treatment

difficulty, it has been suggested⁷ that there could be a tooth size discrepancy in the mandibular arch, which may explain this clinical problem.

Purpose

While numerous studies have been conducted evaluating tooth size and malocclusion,⁴⁻¹¹ genetics,¹²⁻²⁰ gender,^{17,21,22} age,¹⁷ and ethnicity,^{17,21-23} little research has been completed which examines the relationship between tooth size and agenesis.²⁴⁻²⁶ The purpose of this study is to determine if a tooth size discrepancy exists in orthodontic patients with agenesis of the maxillary lateral incisor(s).

Hypothesis

The hypothesis of the present study is that orthodontic patients with unilateral or bilateral agenesis of the maxillary lateral incisor have smaller than average teeth in the maxilla, mandible or both arches when compared to a control group.

CHAPTER II

REVIEW OF LITERATURE

Agenesis of the Maxillary Lateral Incisor

Many terms can be used to describe missing teeth. *Anodontia* is the complete absence of teeth; *Oligodontia* or partial anodontia means absence of six or more teeth; *hypodontia* denotes missing teeth, but usually less than six and often the size and shape of remaining teeth are altered as well,^{12,27} *congenitally missing teeth* or *agenesis* is defined as teeth that failed to develop or are not present at birth. Agenesis of any tooth can cause dental asymmetries, alignment difficulties, and arch length discrepancies but when the missing tooth is in the anterior region of the maxilla, the discrepancies can be quite noticeable.

The maxillary lateral incisor is the second most frequently missing tooth after the mandibular second premolar^{12,21} even though Muller et al. found that maxillary lateral incisors experience the most agenesis (not including third molars).²⁸ Agenesis of the maxillary lateral incisor is also linked with anomalies and syndromes such as agenesis of other permanent teeth, microdontia of maxillary lateral incisors (peg laterals), palatally displaced canines and distal angulations of mandibular second premolars.^{13,29-31}

Restorative Considerations with Agenesis

Absence of any tooth can cause treatment difficulties, but agenesis of the maxillary lateral incisor poses a unique set of restorative challenges. Because the maxillary lateral incisor is located in the esthetic zone, it is essential that bone height, papilla height, enamel color, and shape match the surrounding teeth. Clinicians attempt to maintain the proper anterior overbite, overjet and ideal interarch relationships of the canine teeth while creating enough space for a fixed partial denture or more commonly, an implant with a single crown restoration, but few treatment options are available for patients with agenesis of one or both maxillary lateral incisors. One option is to close the space(s) and restore the remaining teeth accordingly^{32,33} and the second is to open the space for a fixed partial denture or implant.^{1,5,6}

Kokich believes that canine substitution can be an excellent option for some patients, especially if they are Angle Class II with excessive overjet or are Class I with enough crowding in the mandibular arch to warrant extractions.³² The profile of the patients is another factor to consider. Protrusive faces are often more esthetically conducive for canine substitution than creating space for an implant by proclining the incisors and potentially making the lips more protrusive.³² The color and shape of the canines also needs to be taken into account before choosing this as the best option for treatment. If the canines are overly bulky or more yellow in hue than the central incisors, they may need bleaching, enameloplasty or restoration before treatment is complete.^{32,34}

One prosthetic option for replacing the missing lateral incisor is a resin bonded (Maryland) bridge, cantilevered bridge, or full-coverage bridge.¹ Some benefits to these restorations include being less invasive than an implant, they can be completed in a growing individual, and there is more freedom with the space requirements when compared to the minimum of 6mm required for an implant. Kokich reports that the resin bonded bridge is especially conservative since the preparations are only on the lingual of the incisors when compared to the full-coverage abutments of a traditional bridge.¹ A cantilevered bridge is the second most conservative option, followed by the full-coverage bridge. Mobility of the abutment teeth, angulations of the incisors, gingival contours and occlusion are all factors to take into account before choosing one of these treatments for a patient.¹

Replacing the missing lateral incisor with an implant is another prosthetic alternative to closing the space. Kokich states that the smallest implant for this site is about 3.2mm in diameter and recommends having at least 1mm of bone between the implant and adjacent tooth.⁵ Therefore, the implant alone requires at least 5.2mm of space and with the restoration of the crown at least 6mm of space is required. Frequently, clinicians cannot maintain the proper occlusion and create a minimum of 6mm of space for an implant. Kokich advises the interproximal reduction of the central incisors, canines, or premolars to create enough space for an implant when this situation arises.⁵ More recently, he recommended only slenderizing teeth distal to the canines so as not to adversely affect anterior papillae in the esthetic zone.⁷

Overall, the variables considered for restoration of the maxillary lateral incisor depend upon the clinical situation, esthetics and personal preference of

patients and parents. A multidisciplinary approach is necessary in cases of agenesis along with having a predictable treatment plan. While canine substitution may be a viable option for some patients, an implant and crown may be a better treatment plan for others. Since agenesis of teeth has been shown to have a genetic link,¹²⁻²⁰ often parents or siblings of patients experiencing agenesis have had similar clinical situations, which may influence treatment decisions.

Genetics, Tooth Size and Associated Anomalies

Woolf presented data on anomalies associated with agenesis of the maxillary lateral incisor, such as peg laterals.² His study sample consisted of members of the Mormon Church in Salt Lake City because of the extensive family records they keep. Woolf studied 103 participants who had either unilateral or bilateral agenesis of the maxillary lateral incisor, and the relatives of this test group (187 families) from the same area acting as controls. Results showed that 17.7% of parents and siblings of the sample population also had agenesis of the maxillary lateral incisor or peg-shaped laterals, compared to only 2.8% in the control group. Twenty-four of the 103 participants who had agenesis of the maxillary lateral incisor also had a peg-shaped lateral incisor. Members in the same family tended to show the same location and pattern of agenesis (bilateral, unilateral or right versus left). From these results, Woolf concluded that some genotypes result specifically in agenesis of the maxillary lateral incisor, some cause agenesis of multiple teeth, and some cause agenesis of the maxillary lateral incisor and anomalies such as peg laterals. Evidence of a genetic

association was demonstrated in this population; however genetic mapping was not used at the time the study was conducted in 1971 to verify genetic links.

In the 1975 Symposium on Genetics, Bailit presented on variations in tooth size, gender, agenesis and race.¹⁷ The mouth was divided into 3 'groups' per side consisting of incisors (central and lateral), premolars (first and second) and molars (first, second and third). The most distal tooth in each tooth group was shown to be the least stable, except for the mandibular central incisor, and therefore more likely to be congenitally missing. This theory of tooth instability is also known as Butler's Field Theory.³⁵ Bailit theorized that the most distal tooth in a group is more influenced by environmental factors rather than genetics. He believed that genetics had a greater affect on the size of the central incisor, first premolar and first molar whereas the maxillary lateral incisor, second premolar and second molar are more affected by the environment. The last tooth to erupt in a segment (most distal) has a predetermined space in which to erupt, giving it more phenotypic flexibility. Bailit stated that except for the maxillary lateral incisors, tooth sizes are fairly symmetrical bilaterally and when a maxillary lateral incisor is missing, it is most likely the left one. At the time the paper was written in 1975, there was little knowledge about the extent to which genetics affects agenesis, but Bailit suspected it was important.

Since the development of genetic mapping, Brook et al. have shown that some genes are implicated in the agenesis of teeth, including PAX9, MSX1 and AXIN2. The PAX9 gene is on chromosome 14 with a controlling factor for dental development and mutations related to missing teeth.²⁰ Brook et al. measured the tooth sizes on maxillary and mandibular dental casts in the test group, 10 people with

a known PAX9 mutation in one family and 10 people in a control group matched for sex, age and ethnicity, who were not related to the test group and did not have the PAX9 mutation. Differences in the test group with the mutation and hypodontia were found; these teeth were significantly smaller than controls. Canines and first molars were least affected in the test group. This contradicts Bailit's theory that genetics mostly affects the first tooth in each group: the central incisor, canine, first premolar and molar.¹⁷ Brook et al. found that the second tooth in each group was more affected by the PAX9 mutation. The study concluded that the PAX9 mutation not only decreased tooth number, but also tooth size throughout the dentition.

Peck, Peck and Kataja linked palatally displaced canines, transposition of mandibular lateral incisors and canines and maxillary canine and premolar transposition with agenesis.³¹ They studied 161 subjects and found that patients with maxillary canine-first premolar transposition were 13 times more likely (26%) to have agenesis of a maxillary lateral incisor. They agreed with Brook et al. that PAX9 and MSX1 mutations contribute to tooth agenesis²⁰, however they also pointed out that the PAX9 and MSX1 genetic mutations are associated with posterior tooth agenesis while a strong causative gene mutation for anterior agenesis has yet to be found. Peck, Peck and Kataja believe signaling proteins such as bone morphogenic proteins (BMP) and fibroblast growth factor (FGF) may be responsible for agenesis early in embryonic development.

Arte et al. mapped the genes of 77 individuals in 3 generations of Finnish families to determine which genes affect incisor-premolar hypodontia.¹⁶ Thirty-one of the 77 participants expressed incisor-premolar hypodontia; however children

under the age of 6 were excluded from the study because hypodontia cannot reliably be ascertained at that age. They hypothesized that epidermal growth factor (EGF), epidermal growth factor receptor (EGFR), and fibroblast growth factor (FGF-3) genes were responsible for incisor-premolar hypodontia because: 1) EGF has been implicated in early tooth morphogenesis in mice, 2) EGFR is expressed in developing teeth from the bud stage onward, and 3) FGF-3 is intensely expressed in dental mesenchyme during cap and bell stages of tooth development. However, after extracting DNA from blood samples of the participants and running PCR procedures, results did not show that these genes are involved in incisor-premolar hypodontia. They concluded that mutations in EGF, EGFR, FGF-3 and FGF-4 did not influence incisor-premolar hypodontia in the families studied.

Pirinen et al. focused their research on palatally displaced canines and agenesis of incisors and premolars.²⁹ They examined 106 patients (77 females, 29 males) who had undergone surgical exposure of a palatally impacted canine to determine whether they also expressed agenesis. One hundred and ten first-degree relatives of these patients and 93 second-degree relatives were also examined while pedigrees were created to establish a genetic link. Results showed that 36% of the test patients exhibited agenesis, which is 4.5 times the population prevalence. First and second-degree relatives showed 19-20% agenesis or 2.5 times the population prevalence. This illustrates that there is a strong genetic link between palatally displaced canines and agenesis.

Arte et al. also found strong genetic relationships between hypodontia and tooth anomalies such as ectopic maxillary canines.³⁰ They studied 11 people (aged

10-36 years) with hypodontia of 1 to 6 permanent teeth and their relatives, totaling 214 Finnish individuals. The mean number of tooth agenesis in the test group was 2.3 and 1.7 in their families indicating a strong genetic link. Data was collected retrospectively through dental history and radiographs and the controls were established with published population prevalence. Results showed 4.5-4.9 times the occurrence of hypodontia in first and second degree relatives (39% and 36% respectively). They also found an equal maternal and paternal inheritance. Rotated premolars and ectopic permanent canines were seen more frequently in patients with hypodontia and their families; 2 to 3 times that seen in the general population. The authors concluded that incisor-premolar hypodontia is associated with many dental anomalies and is transmitted in an autosomal dominant manner.

Dempsey and Townsend aimed to quantify the relative contributions of the environment and genetics to the mesio-distal (MD) and buccal-lingual (BL) sizes of teeth in monozygotic and dizygotic twins.¹⁸ The MD and BL of 596 participants' teeth were measured on plaster casts. Different model analyses were created to separate twin pairs of males and females, monozygotic twins that were raised apart (different environments), and dizygotic twins. Mandibular lateral incisors were found to be the least sexually dimorphic permanent teeth. For most teeth, the variation in crown size can be explained by the additive genetic and unique environmental variation. Environmental influences on tooth crown size can be substantial, but heritability of most crown sizes is moderate to high.

In summary, the research on how genetic factors relate to tooth size and agenesis indicates that they are highly correlated. Genetic factors appear to play a

large role in tooth size and agenesis with the PAX9 and MSX1 mutations; however some authors suspect that the local environment is important factor. EGF, EGFR, FGF-3 and FGF-4 are not shown to be linked to incisor-premolar agenesis,¹⁶ but it is possible that signaling factors early in embryologic development may contribute to agenesis. Through the work of Pirinen et al. and Arte et al., it is evident that incisor-premolar hypodontia is genetically inherited, with strong links to other dental anomalies such as palatally impacted canines.^{29,30} Incisor-premolar hypodontia is an autosomal dominant gene inheritance with incomplete penetrance.¹⁶

Gender and Ethnicity

Bailit investigated dental variation among populations to discover that people from Asian ancestry have large maxillary lateral incisors compared to their central incisors and ‘blacks’ and ‘whites’ have very different tooth sizes.¹⁷ However, the terms ‘black’ and ‘white’ that he uses in his research are misleading because of the subgroups and potential variation in each ethnicity. Eruption patterns also vary amongst races, with people of African descent showing earlier tooth eruption than people from European descent. Males also have larger teeth than females, with canines up to six percent larger than their female counterparts.

Smith et al. came to similar conclusions as Bailit. He studied Bolton’s ratios in 3 populations who did not have orthodontic treatment: ‘black’, ‘Hispanic’, and ‘white’ samples.²² He found that Bolton’s ratios applied best to white females, but the ratios could not be applied to white males, black or Hispanic populations. The teeth causing the most variability in Smith’s study were: maxillary lateral incisors,

maxillary second premolars, mandibular second premolars, and mandibular central incisors, which agrees with Butler's Field theory.³⁵ White populations were found to have the smallest teeth followed by Hispanic and then black populations. Smith et al. also suggested that Bolton ratios should not be applied to white male, black or Hispanic populations.

Bishara et al. measured dental casts from Northern Mexican and Caucasian children.²³ Twenty-six males (mean age 12.5) and 34 females (mean age 12.9) made up the Mexican group with 35 males (mean age 13.8) and 22 females (mean age 14.2) for the Caucasian test group. Tooth-size discrepancies between genders of each ethnicity were noticed, as male Caucasians were found to have larger canines and first molars than female Caucasians, and male Mexicans had significantly larger canines, first premolars, second premolars and first molars than Mexican females. However, no difference was found between incisors of either group.

The conclusions from these studies can be summarized as such: different ethnicities have different sized teeth, with evident patterns in each population. Likewise, males generally have larger teeth than females within any given ethnicity. Therefore, it is not advisable to blend samples of various races and genders, especially when one is concerned with tooth size.

Malocclusion and Tooth Size

Bolton was one of the first authors to study tooth sizes within an arch and establish dental ratios.^{4,8} There are conflicting reports in the literature supporting or negating Bolton's 'standards' but the data and methods that he developed in the

1950s are still used today. Bolton measured the mesio-distal widths of teeth on 55 dental casts with 'excellent occlusions'. Forty-four of them had been treated orthodontically, while eleven had not. Bolton did not attempt to control his study group's dental casts sample for age, gender or race. Since his study in 1952, it has become increasingly evident that gender and race affect tooth size, and age plays a role in tooth size if attrition is involved.¹⁷ After measuring the mesial-distal widths of the teeth, he divided the sum of the mandibular anterior teeth by the sum of the maxillary anterior teeth to determine an anterior ratio. He did the same for the complete dental arch (first molar to first molar) by dividing the sum of the widths of the mandibular 12 teeth by the sum of the maxillary 12 teeth. The anterior ratio he described was 77.2 and the overall ratio was 91.3. Bolton established standards for tooth size allowing practitioners to observe if a patient had a tooth-size discrepancy; however, subsequent research has shown that these ratios apply best to Caucasian females.²²

Ballard also evaluated tooth sizes and discussed the etiology and relation to malocclusion.⁹ He measured the mesio-distal width of teeth on 500 plaster casts and, like Bolton,^{4,8} did not disclose or identify the age, gender, or race of the samples. Ballard's results showed that 90% of the teeth in his sample were not symmetric in size between right and left sides, with a tooth-size discrepancy of 0.25mm or more between the same teeth on opposite sides of the dental arch. His clinical suggestion was to use judicious interproximal reduction to achieve balance within a dental arch. Ballard was not suggesting that this discrepancy causes malocclusion or orthodontic

relapse, but if imbalance was evident while trying to align teeth, a tooth-size discrepancy would likely be present.

Nie and Lin conducted a study in 1999 to determine if there was a Bolton discrepancy within varying malocclusions.³⁶ Three hundred casts from Chinese patients made up their test group, which were divided by malocclusion: Angle Class I, II or III. Mesio-distal dimensions of the teeth were measured and the Bolton analysis was performed on each case. Differently than other studies,^{17,22,23} they found no significant gender differences within each group as related to tooth size, so males and females were combined in each group. Nie and Lin discovered that Angle class III malocclusions tended to have larger mandibular than maxillary incisors and Angle class II malocclusions had larger maxillary than mandibular incisors. The class I cases in their study had bimaxillary protrusion and showed no intermaxillary tooth size discrepancy. They advocate using the Bolton analysis to diagnose possible contributors to dental malocclusion, such as a tooth size discrepancy.

In 2001, Basdra et al. investigated a relationship between Class III and Class II division 1 malocclusions who had not received orthodontic treatment and congenital tooth anomalies.¹⁵ They examined 215 total patients with these malocclusions looking for: maxillary incisor hypodontia, maxillary canine impaction, transpositions, supernumerary teeth, and tooth agenesis. The age range of the patients was 7.2-45.8 years, roughly half males and half females. A dental history and radiographs were used to confirm the tooth anomalies. While 5.5% of the Class III patients and 1.9% of the CL II division 1 patients presented with agenesis of their maxillary lateral incisors, the frequency was not different from that of the general

population. In fact, none of the anomalies in these two malocclusion groups showed variance from that in the normal population; results were not statistically significant.

Uysal et al. sought to determine if gender differences could be found in tooth size between Angle Class I, II and III malocclusions.¹⁰ The samples in their study consisted of 150 dental casts from a Turkish population with normal occlusions and 560 casts with varying malocclusions. About half were male with a mean age of 22.09 years and half were female with a mean age of 21.11 years. The Bolton ratio calculation and norms were used to determine any level of a significant discrepancy in tooth size within the study populations. The researchers combined males and females because no gender differences were evident between the two malocclusion groups, but they did notice differences in tooth size between genders in the normal occlusion group. Results showed no statistically significant difference in tooth size among the different malocclusion groups.

No firm conclusions can be drawn on whether tooth size can determine or affect malocclusions such as Angle Class II or III, but trends have been seen in certain populations. Nie and Lin did find Class II patients to have larger maxillary than mandibular anterior teeth and vice versa for Class III patients. However, Uysal et al. found no difference in Bolton discrepancies between Angle Classifications. Each study was conducted with dental casts from different ethnic groups, which could be a variable that makes them incomparable. Malocclusion group and dental anomalies are not shown to be related.¹⁵

Agenesis and Tooth Size

Sofaer et al. in 1971 provided one theory on tooth size and agenesis.²⁵ He measured the teeth of 17,000 high school students in Hawaii ranging in age from 11-20 years, some with agenesis of the maxillary lateral incisor and some with a full complement of teeth. Teeth were measured intra-orally with oral proof of agenesis; no radiographs were taken of the subjects. Peg laterals were associated with a smaller than normal central incisor adjacent to it. A missing lateral incisor tended to have a larger than normal central incisor adjacent. Central incisors were more asymmetrical than normal in cases of a missing lateral incisor and were also slightly, but not significantly, larger than normal when maxillary lateral incisors were bilaterally missing. Sofaer hypothesized that the size of the lateral incisor depends on the amount of space the central and canine have left for it during primordial development. Since the canine and central incisors develop before the lateral incisor, he theorized that it must compete with its neighbors for size. Sofaer believed that inadequate environment, poor primordium or both may cause this tooth size asymmetry.

In contrast to Sofaer, Baidas and Hashim found that maxillary anterior teeth were smaller than normal in patients with unilateral or bilateral agenesis of maxillary lateral incisor.²⁶ Thirty dental cases were measured, 12 had a missing lateral incisor unilaterally, 18 had missing lateral incisors bilaterally. However, the test population race was not disclosed and male and female measurements were analyzed together. The authors used Bolton's analysis^{4,8} and Wheeler's index³⁷ to evaluate anterior maxillary and mandibular tooth size ratios. The Bolton Index ratios were larger for

patients with bilateral or unilateral agenesis of a maxillary lateral incisor (79.1% and 81.7% respectively with the norm of 77.2%); thus demonstrating lack of maxillary tooth structure. The reliability of Bolton ratios on racially unknown study population should be questioned, mainly because Bolton ratios have been shown to best apply to Caucasian females.²²

Le Bot's study found similar results as Baidas and Hashim.²⁴ He measured the teeth of 200 French males with maxillary lateral incisor agenesis confirmed radiographically. The sum of the bucco-lingual and mesio-distal dimensions of maxillary teeth in dental arches with the agenesis of a lateral incisor were shown to be significantly smaller than normal. Interestingly, dental arches in the test group who experienced 'peg' laterals with no agenesis expressed even smaller teeth than the group with agenesis. Premolars and canines within the arch showed the greatest reduction in dimensions when the maxillary lateral was missing; molars were least affected. Le Bot also noted that 39.6% of the test sample with agenesis had a missing a third molar compared to 12.4% in the control group.

In 2007, Othman and Harradine studied tooth size discrepancies in an orthodontic population to determine how frequently they occur, the amount of discrepancy that is clinically significant and if these discrepancies can be visually evaluated without measurement (recommended by Bosio³⁹ and Proffit²⁷).³⁸ Their population did not contain agenesis, but complete, permanent dentitions. They measured the mesio-distal widths of teeth on 150 (96 female, 54 male) pretreatment casts from Caucasian patients and used the Bolton Analysis⁴ to calculate tooth size discrepancies. Othman and Harradine found that in this orthodontic population,

17.4% of people had anterior ratios and 5.4% had total tooth-width ratios greater than 2 standard deviations from Bolton's norms. They believe that Bolton's selection criteria may have skewed his results because he chose his sample based on 'excellent occlusions',⁴ which is not typical for an orthodontic practice. The authors also determined that 2mm of tooth size discrepancy within an arch (1mm per side) is considered clinically significant, compared to other literature stating a discrepancy of 1.5mm per arch is clinically significant.²⁷ They also concluded that visualization of a tooth size discrepancy by comparing the size of the maxillary lateral incisor to the size of the mandibular lateral incisor is not an accurate method of evaluating tooth size discrepancies. Thirty percent of teeth visually examined this way were deemed not to have a discrepancy even though measurements showed they did have a significant tooth size deficiency.

To summarize the studies presented on tooth size and agenesis: tooth size discrepancies do exist in combination with agenesis of a maxillary lateral incisor. Central incisors adjacent to the missing lateral incisors were larger than 'normal' in an early, intra-oral study,²⁵ whereas other studies measuring teeth on dental casts showed smaller than average maxillary anterior teeth when the lateral incisor was missing.^{24,26} Premolars and canines within the arch with agenesis have also been shown to be smaller than normal and third molar agenesis is more common as well.²⁴ In an orthodontic population without agenesis, tooth size discrepancies are fairly common. About 17.4% of patients have tooth size discrepancies in the anterior region of the arch and 5.4% have discrepancies in the total arch when compared to

Bolton's standards.³⁸ Two millimeters of discrepancy per arch is considered clinically significant.³⁸

CHAPTER III

MATERIALS AND METHODS

This research was approved by the IRB committee at Marquette University under the ‘exempt’ category in December of 2009. A literature review was conducted on Pub Med, The Cochrane Libraries, American Dental Association Library, and the American Journal of Orthodontics and Dentofacial Orthopedics websites looking for relevant articles using the key words: agenesis, maxillary lateral incisors, missing teeth, tooth size, peg laterals. From these results, a review of the literature was compiled.

In December 2009, the principle investigator (PI) sent letters to orthodontists in the Greater Milwaukee area asking for them to provide dental casts of patients’ teeth that met the inclusion criteria for this study (see Appendix A for letter). The inclusion criteria for the test population was as follows: Caucasian patients with unilateral or bilateral agenesis of maxillary lateral incisor(s), first molar to first molar teeth fully erupted (except for the agenesis of one or both maxillary lateral incisors), no extreme wear, breakdown, or interproximal reduction of any teeth. Some doctors only had post-treatment casts available for measurement, in which case they verified that no interproximal reduction or enameloplasty had been conducted during treatment. If any tooth had a crown or a significantly large restoration, that set of casts was rejected due to the modification of tooth structure and size.

Only plaster casts were utilized in this study. Although there is no statistically significant difference in size when measuring plaster casts versus digital

casts, a small discrepancy was found (0.4mm).⁴⁰ This discrepancy could have potentially been significant for the measurement purposes of this study especially if some of the dental casts were digital and others plaster. For this reason, only plaster casts were accepted. Some of the dental casts were soaped, however the difference in size of teeth on soaped versus unsoaped casts is nominal (0.08mm).⁴¹



Figure 1: Casts of a patient exhibiting unilateral agenesis of left maxillary lateral incisor, retained left primary canine, left permanent canine in the position of lateral incisor and a peg-shaped right lateral incisor.

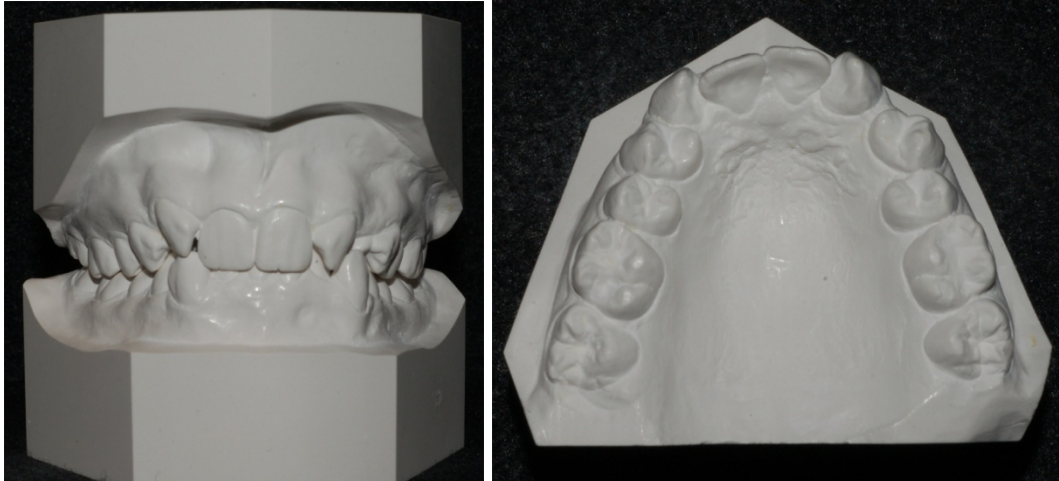


Figure 2: Casts of a patient with agenesis of both maxillary lateral incisors. Maxillary canines are mesialized into the lateral incisors' space.

Forty sets (21 females and 19 males) of maxillary and mandibular dental casts with agenesis of one or both maxillary lateral incisors were gathered from January to June of 2010. The mean age for the test group was 15.936 years (SD=7.12) ranging from 11 to 47 years old. (Table 1) Twenty-two patients expressed unilateral agenesis of the maxillary lateral incisor, while 18 had bilateral agenesis. The orthodontists who contributed the dental casts for the sample provided the age of the patients at the time the casts were taken, gender and race of the patients. A high-precision digital caliper (Masel Electronic digital calipers, Bristol, PA) was used to measure the mesio-distal widths of each tooth with measurements rounded to the nearest hundredth of a millimeter. (Figure 3) To test the reliability of the measurements, two casts from the test group were measured at three different time points, each two months apart. After the teeth were measured, the dental casts were returned to the orthodontists.

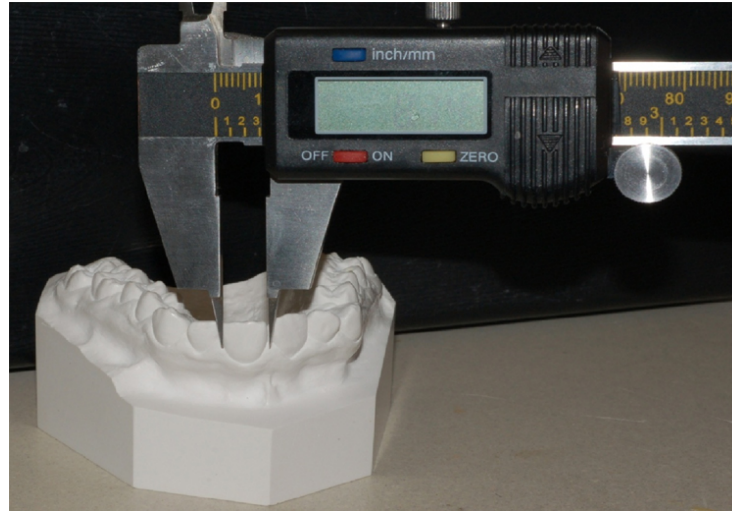


Figure 3: Digital caliper measuring mesio-distal widths of maxillary teeth. The teeth were measured at their widest point.

A control group of 40 sets of dental casts was collected from Marquette University's Orthodontic department after the test group was established. The PI searched for males and females on the orthodontic department's computerized charting system (AxiUm) that met the age, race, and gender of the test population. The mean age for the control group was 15.925 years (SD=6.74). (Table 1)

Group	Mean Age	SD
Overall	15.931	6.89
Control	15.925	6.74
Test	15.936	7.12

Table 1: Mean age and standard deviation (SD) for test and control groups

Male and female teeth were analyzed separately for most of the tests because of reported tooth-size-differences between genders.^{17,21,22}

CHAPTER IV

RESULTS

The hypothesis was proven to be correct; people experiencing agenesis of the maxillary lateral incisor(s) do exhibit smaller than normal tooth size. In the test groups for males and females, all of the teeth in the maxillary arch were smaller when compared to the control group. However, not all of these differences were statistically significant. (Tables 2 and 4) The independent t-test was used to analyze the data for most of the tooth-width measurements because the data was normally distributed and the test and control groups for this study were independent.

The independent t-test is only valid if the data are normally distributed. In cases where this assumption is violated, the nonparametric alternative to the independent t-test is used, which is the Mann-Whitney test. While the purpose of the independent t-test is to determine if the means of the control and test groups are significantly different, the Mann-Whitney simply determines if the distribution of the two groups is different. The Mann-Whitney test was used in samples that were not normally distributed such as the data for male UL2, female UL2, UR2 and LR1. (Tables 2, 4 and 5)

Males in the test group had significantly smaller maxillary posterior teeth (U4s, 5s and 6s) when compared to males in the control group, with differences in posterior tooth size ranging from 0.28-0.78mm. (Table 2) In the male samples exhibiting unilateral agenesis of a lateral incisor, the contra lateral maxillary lateral incisor was also significantly smaller than the control group's maxillary lateral incisors. Differences between test and control mean mesiodistal tooth widths were 2.09mm for the UL2 and 0.96mm for UR2. (Table 2) Aside from smaller than

average maxillary lateral incisors if one was missing, males in the test population did not show any significant anterior tooth-size discrepancy when compared to the controls.

Tooth	Group	n	Mean	SD	Test Statistic	P-value
UL6	Control	19	10.36	0.70	t(36)=2.17	0.0364*
	Test	19	9.85	0.76		
UL5	Control	19	6.73	0.37	t(36)=2.21	0.0332*
	Test	19	6.43	0.45		
UL4	Control	19	7.13	0.40	t(36)=2.27	0.0291*
	Test	19	6.77	0.56		
UL3	Control	19	7.90	0.60	t(36)=1.32	0.1956
	Test	19	7.66	0.52		
UL2	Control	19	6.82	0.53	z= -3.60	0.0003**
	Test	6	4.73	1.27		
UL1	Control	19	8.67	0.71	t(36)=0.47	0.6389
	Test	19	8.56	0.71		
UR1	Control	19	8.61	0.70	t(36)=0.22	0.8269
	Test	19	8.55	0.74		
UR2	Control	19	6.79	0.60	t(21)=2.66	0.0146*
	Test	4	5.83	0.93		
UR3	Control	19	8.03	0.57	t(36)=1.36	0.1834
	Test	19	7.79	0.51		
UR4	Control	19	7.10	0.35	t(29.79)=2.14	0.0410*
	Test	19	6.77	0.58		
UR5	Control	19	6.80	0.42	t(36)=2.16	0.0378*
	Test	19	6.52	0.37		
UR6	Control	19	10.49	0.74	t(36)=2.11	0.0422*
	Test	19	10.04	0.53		

Table 2: Male maxillary arch tooth measurements (test and control) UL= Upper Left, UR= Upper Right. The numbers identify teeth from the midline (central incisor=1) to the posterior (first molar=6). Independent t-test was used to analyze the data, except for UL2 where the Mann-Whitney test was used because the data was not normally distributed.

*indicates significance at $p \leq 0.05$, ** indicates significance at $p \leq 0.01$

Males in the test group did experience smaller than average teeth in the mandibular arch, but results were asymmetrical. LL4, LL2, LL1 and LR2 were significantly smaller than the control group's teeth sizes with differences of 0.32mm, 0.32mm, 0.32mm and 0.38mm respectively. (Table 3)

Tooth	Group	n	Mean	SD	Test Statistic	P-value
LL6	Control Test	19 19	11.24 11.10	0.89 0.61	t(36) = 0.57	0.5739
LL5	Control Test	19 19	7.28 7.16	0.47 0.46	t(36) = 0.75	0.457
LL4	Control Test	19 19	7.22 6.90	0.48 0.47	t(36) = 2.06	0.0464*
LL3	Control Test	19 19	6.95 6.65	0.45 0.57	t(36) = 1.84	0.0737
LL2	Control Test	19 19	5.95 5.63	0.38 0.41	t(36) = 2.42	0.0208*
LL1	Control Test	19 19	5.42 5.10	0.34 0.49	t(36) = 2.36	0.0235*
LR1	Control Test	19 19	5.40 5.22	0.32 0.47	t(36) = 1.36	0.1833
LR2	Control Test	19 19	5.96 5.58	0.43 0.50	t(36) = 2.54	0.0155*
LR3	Control Test	19 19	6.98 6.68	0.48 0.62	t(36) = 1.65	0.107
LR4	Control Test	19 19	7.15 6.88	0.50 0.54	t(36) = 1.65	0.1074
LR5	Control Test	19 19	7.26 7.12	0.47 0.46	t(36)=0.89	0.38
LR6	Control Test	19 19	11.20 11.07	0.90 0.63	t(36)=0.50	0.6196

Table 3: Male mandibular arch tooth size measurements (test and control) LL= Lower Left, LR= Lower Right. The numbers identify teeth from the midline (central incisor=1) to the posterior (first molar=6). Independent t-test was used to analyze all data.

*indicates significance $p \leq 0.05$

In contrast to the test group males with a smaller tooth-size trend in the posterior area, females in the test group expressed smaller teeth in the anterior maxilla. Independent t-test showed that females in the test group had significantly smaller maxillary left (UL3) and right (UR3) canines and maxillary left central incisor (UL1) when compared to the control group. Differences in test versus control group were 0.22mm, 0.24mm and 0.42mm, respectively. The right maxillary lateral incisor (UR2) was also significantly smaller if the contra-lateral tooth was missing, with a difference of 1.32mm compared to the control. Even though the left maxillary lateral incisor (UL2) was 0.7mm smaller than the mean UL2 of the control group, this difference was not statistically significant. (Table 4) For the female mandibular arch, the only tooth that was smaller than normal when compared to the control group was LL2 with a difference of 0.25mm. (Table 5)

Tooth	Group	n	Mean	SD	Test Statistic	P-value
UL6	Control	21	9.94	0.43	t(40) = 0.10	0.9194
	Test	21	9.92	0.56		
UL5	Control	21	6.56	0.42	t(40) = 0.50	0.6206
	Test	21	6.49	0.45		
UL4	Control	21	6.92	0.44	t(40) = 0.50	0.6184
	Test	21	6.85	0.41		
UL3	Control	21	7.54	0.33	t(40) = 2.08	0.0442*
	Test	21	7.32	0.37		
UL2	Control	21	6.52	0.38	z = -1.83	0.671
	Test	7	5.82	1.37		
UL1	Control	21	8.62	0.60	t(40) = 2.34	0.0241*
	Test	21	8.20	0.57		
UR1	Control	21	8.60	0.58	t(40) = 1.74	0.0889
	Test	21	8.27	0.65		
UR2	Control	21	6.55	0.39	z = -2.93	0.0034**
	Test	5	5.23	0.86		
UR3	Control	21	7.63	0.37	t(40) = 2.03	0.0487*
	Test	21	7.39	0.40		
UR4	Control	21	6.95	0.37	t(40) = 1.00	0.3227
	Test	21	6.81	0.43		
UR5	Control	21	6.55	0.44	t(40) = 0.45	0.6523
	Test	21	6.49	0.40		
UR6	Control	21	10.01	0.36	t(31.53) = 0.54	0.5917
	Test	21	9.92	0.64		

Table 4: Female maxillary arch tooth size measurements (test and control). UL= Upper Left, UR= Upper Right. The numbers identify teeth from the midline (central incisor=1) to the posterior (first molar=6). Independent t-test was used to analyze all teeth except UL2 and UR2, where the Mann-Whitney test was used because the data for UL2 and UR2 were not normally distributed.

*indicates significance at $p \leq 0.05$, ** indicates significance at $p \leq 0.01$

Tooth	Group	n	Mean	SD	Test Statistic	P-value
LL6	Control	21	10.65	0.47	t(40) = -0.93	0.3566
		21	10.80	0.56		
LL5	Control	21	7.05	0.39	t(40) = -0.20	0.8423
		21	7.08	0.42		
LL4	Control	21	7.05	0.48	t(40) = 0.60	0.5493
		21	6.96	0.41		
LL3	Control	21	6.54	0.31	t(40) = 1.29	0.2031
		21	6.42	0.28		
LL2	Control	21	5.86	0.34	t(40) = 2.34	0.0243*
		21	5.61	0.37		
LL1	Control	21	5.27	0.34	t(40) = 1.48	0.1459
		21	5.11	0.36		
LR1	Control	21	5.29	0.36	z = 1.85	0.0643
		21	5.08	0.38		
LR2	Control	21	5.84	0.34	t(40) = 2.00	0.525
		21	5.63	0.38		
LR3	Control	21	6.55	0.32	t(40) = 1.53	0.1338
		21	6.37	0.41		
LR4	Control	21	7.07	0.49	t(40) = 0.77	0.4452
		21	6.96	0.43		
LR5	Control	21	6.99	0.32	t(40) = -0.56	0.58
		21	7.06	0.49		
LR6	Control	21	10.66	0.46	t(40) = -0.86	0.3946
		21	10.79	0.57		

Table 5: Female mandibular arch tooth size measurements (test and control). LL= Lower Left, LR= Lower Right. The numbers identify teeth from the midline (central incisor=1) to the posterior (first molar=6). Independent t-tests were used to analyze all teeth except LR1 where the Mann- Whitney test was used because the measurements for LR1 were not normally distributed.

*indicates significance at $p \leq 0.05$

When a patient in the test group was missing one maxillary lateral incisor, the opposite lateral incisor was significantly smaller than normal on average, frequently referred to as peg-shaped. (Figure 1) The average size of a maxillary lateral incisor in

the control group was 6.66mm wide, but in the test group, the average size was 5.39mm (difference of 1.27mm). (Table 6) When males and females were analyzed separately, they both showed statistically significant smaller than normal maxillary lateral incisors.

Gender	Tooth	Group	n	Mean	SD	Test Statistic	P-value
Both	U2s	Control	80	6.66	0.49	t(23)=4.91	<0.0001**
		Test	22	5.39	1.19		
Female	U2s	Control	42	6.53	0.38	t(11.67)=2.78	<0.0001**
		Test	12	5.58	1.18		
Males	U2s	Control	38	6.81	0.56	t(40) = 1.74	0.0021**
		Test	10	5.17	1.23		

Table 6: Maxillary peg lateral incisors in the test group compared to the control group. U2= maxillary lateral incisor. Both right and left sides were tested together using independent t-tests.

*indicates significance at $p \leq 0.05$, ** indicates significance at $p \leq 0.01$

A reliability statistical test was calculated to determine the consistency the PI's measurements. This test is often calculated to determine the similarity of measurements made by multiple people. For the present study, the intra-rater reliability, or the consistency of measurements made by the same person multiple times, needed to be determined. To do this, the intra-rater version of the Shrout-Winer reliability statistic was used. The values of this statistic can range between 0 and 1, where 0 indicates no reliability and 1 indicates perfect reliability. The resulting statistic was 0.99419, confirming the test to be extremely reliable.

CHAPTER V

DISCUSSION

The goals of orthodontic treatment in cases with anterior tooth agenesis are: to establish the proper occlusal relationships of the canine through molar teeth, to establish proper anterior overbite and overjet, and to open 'enough' space for an implant (or less commonly, a fixed partial denture). While many orthodontists allow the implant size to determine the space required for a missing lateral incisor, few take into consideration the shape and size of adjacent teeth. Even though clinicians discuss having 'enough' space for an implant, the main focus should be on having the 'appropriate' space for an implant/restoration. The 'Golden Proportion' (as discussed in the introduction) for the anterior teeth needs to be evaluated when determining the size of a restoration for the missing lateral incisor.³ If a patient has smaller than normal anterior teeth, as was shown in the female test sample of the present study, it is possible that while 6.5mm or 7mm is appropriate for an implant, it may be too large for a lateral incisor when compared to the adjacent teeth. This validates the purpose of this study so clinicians can properly plan for restorative work and appropriate space creation in patients with agenesis of one or both maxillary lateral incisors.

The purpose of this study was to determine if a tooth size discrepancy exists in the maxillary, mandibular or both arches in orthodontic patients when the maxillary lateral incisor(s) fail to develop. The hypothesis was proven to be correct. An association between agenesis of maxillary lateral incisors and tooth size was

found. Results showed that males experienced smaller posterior teeth when compared to the control group (U4s, 5s and 6s), while females showed smaller than normal anterior teeth (UL3, UR3, UL1).

It is unclear why the mean size of the female right maxillary central incisor (UR1) was not statistically significantly smaller than the control, as was shown with the left central incisor. This finding could be the result of the small sample size (n=40 in test group) and it is possible that with a larger sample, the mean for female UR1 would have been smaller than the control group's mean. Or, the present study's finding could accurately display asymmetry within the maxillary dental arch. Ballard discovered that 90% of teeth in his sample were not symmetrically sized between right and left sides with differences as much as 0.25mm.⁹ This study did not corroborate the 90% Ballard showed, but tooth size differences were evident within the dental arches.

Asymmetry in tooth size was also observed in the male and female test group mandibular arches. Teeth that were smaller for males in the test group were: LL4, LL2, LL1 and LR2. Females had smaller than normal LL2 when compared to the control group. These smaller than normal measurements of the mandibular teeth may be due to variability within the sample, or they may demonstrate that mandibular teeth are affected by maxillary agenesis. Because these trends were different between males and females in the present study, it could suggest a sex-linked genetic association between agenesis and tooth size as suspected by Brook.²⁰

Both males and females had smaller than average lateral incisors if the contra lateral tooth was missing, which confirmed the link between peg lateral incisors and

agenesis.^{2,27} Even though the present study evaluated mean mesiodistal widths of each tooth within a group, it is interesting to note the large range of maxillary lateral incisor size in cases of unilateral agenesis (2.9mm-6.95mm). This demonstrates a wide spectrum in tooth size of the maxillary lateral incisor if the contra lateral one is congenitally missing.

A Bolton analysis was not conducted on the teeth in the test group in this study because of the maxillary lateral incisor agenesis. However, Kokich advocates using the Bolton analysis to determine the appropriate size for the replacement of the missing maxillary lateral incisor.¹ He suggests dividing the sum of the widths of the mandibular anterior teeth by the sum of the maxillary anterior teeth plus 'x' (the missing tooth) and setting it equal to the ideal anterior Bolton ratio (0.78). He then solves for 'x'. This works well in patients with appropriately sized anterior teeth to guide clinicians on the size that the missing lateral incisor should be. However, in a population with a suspected tooth size discrepancy, using the ideal anterior Bolton ratio of 0.78 would not identify such a discrepancy and could suggest that the missing lateral incisor be larger or smaller than 'normal'. Another problem with this equation is that 'x' (the size of the missing lateral incisor) may not match that of the contra lateral maxillary lateral incisor that is present. This could mislead the clinician into preparing an incorrect amount of space during treatment for the implant and crown restoration.

Kokich's method was not used to solve for 'x' in this study. It would have been inaccurate to extrapolate the size of the missing lateral incisor based on the size of the opposite lateral incisor to properly conduct the Bolton analysis and determine

if a tooth size discrepancy existed in this sample. The incidence of peg lateral incisors in patients with incisor agenesis has already been documented² and was confirmed in this study. Given the fact that peg laterals are smaller than normal, inclusion of their measurements could have skewed the Bolton analysis results. Likewise, Smith et al. determined that Bolton's ratios best applied to Caucasian females,²² which also could have negatively affected the results of this study had they been applied to Caucasian males in this sample. Thus, the Bolton analysis was considered unreliable for the purposes of this study.

Even though some of the results of the present study are statistically significant they may not be clinically significant. A tooth size discrepancy of 1.5-2mm within an arch (0.75-1mm/side) is deemed clinically significant.^{27,38} However, both Proffit and Othman utilized the Bolton analysis to determine this clinical significance, which was not applied in the present study for reasons previously mentioned. Othman's study was conducted in a sample of orthodontic patients who had a full complement of teeth, which also makes it hard to compare to the present study. Because the present study evaluated the means of each tooth and did not calculate the tooth size discrepancy per patient (as one would perform with the Bolton analysis), it is difficult to determine if the results from this sample are clinically significant.

The present study does show statistically smaller teeth in patients with agenesis of the maxillary lateral incisor. However, these findings may have variability between patients and depend on each specific clinical situation. It is advisable to approach each patient with agenesis on a case-by-case basis knowing

that patients with agenesis can have patterns of smaller than normal teeth. These tooth size reductions may be clinically significant for some patients (1.5-2mm discrepancy within an arch) but not for others.

It would be interesting for future research to evaluate tooth size and the effects on the final occlusion. Because the present study aimed to limit alterations to tooth size that can happen during orthodontic treatment (such as interproximal reduction), pre-treatment casts were measured instead of post-treatment casts without evaluating the final occlusal result. Tooth size discrepancy may have been visually obvious had post-treatment casts and the occlusion been evaluated.

It is difficult to generalize these findings and tooth size discrepancy patterns across races, since this study was limited to male and female Caucasian orthodontic patients. The present sample showed significantly smaller teeth in the anterior maxilla of Caucasian females and posterior maxillary segments of Caucasian males. However, people of African, Hispanic or Asian decent may show different tooth size discrepancies with agenesis of the maxillary lateral incisor(s) or none at all. Future studies are recommended to evaluate these populations.

CHAPTER VI

CONCLUSIONS

The hypothesis of the present study was proven to be correct; orthodontic patients with unilateral or bilateral agenesis of the maxillary lateral incisor can have smaller than average teeth in the maxilla, mandible and both arches when compared to a control group. The patterns of the smaller tooth size demonstrated in this study are highlighted below.

- In males, maxillary lateral incisor agenesis is associated with significantly smaller than average posterior maxillary teeth (first molars, first and second premolars) bilaterally.
- The male mandibular arch showed asymmetrically smaller teeth when compared to the control group (left first premolar, left lateral incisor, left central incisor and right lateral incisor).
- Females with maxillary lateral incisor agenesis demonstrated smaller than normal maxillary anterior teeth (right and left canines and left central incisor).
- The female mandibular arches only showed smaller left lateral incisors when compared to the control group.
- If orthodontic patients experienced unilateral agenesis of the maxillary lateral incisor, the contra lateral maxillary lateral incisor was significantly smaller than normal, indicating a 'peg' shape. This was evident in both genders.

- On average, the difference in maxillary lateral incisor size (when the contralateral one was missing) was 1.27mm compared to the control with a range in tooth sizes of 2.9-6.95mm.
- Interproximal reduction of teeth distal to the canine may be indicated in patients with a tooth size discrepancy in order to create the appropriate space for restoration of a missing maxillary lateral incisor.

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Appendix A

Dear Doctor:

My name is Jane Wright and I am an orthodontic resident in Marquette University's graduate training program. For my masters research project at Marquette, I am studying patients with congenitally missing maxillary lateral incisors (unilaterally or bilaterally) and evaluating for a tooth-size discrepancy. We feel there is some anecdotal evidence (Kokich 2009) that there is a generalized tooth size discrepancy in patients with congenitally missing lateral incisors. I need to collect as many study casts of patients missing their maxillary laterals as possible (at least 30 casts) to measure the dimensions of the teeth. All patient information will be safeguarded and the proper IRB approval has been obtained.

The inclusion criteria for the patients' casts are:

1. **Missing one or both maxillary lateral incisors**
2. **Caucasian**
3. **Any age patient**
4. **Male or female**
5. **Initial (pre-treatment) casts of both upper and lower arches**
6. **Full permanent dentition or at least the majority of each tooth must be erupted (except second and third molars)**
** if the patient's initial casts are of mixed dentition, insufficient, or lost, final casts may be used as long as interproximal reduction has not occurred.*
7. **Little to no wear on the teeth**
8. **No obvious proximal restorations or crowns**

In an attempt to eliminate variables, only plaster casts will be used (no digital).

Please let me know if you have any patient casts that meet the inclusion criteria. I can either visit your office to measure the casts (if you would rather they don't leave your office) or I could pick them up and measure them here, at Marquette University in the Orthodontic Department. If you are a part-time faculty member here at Marquette, another option would be for you to bring the casts to this department.

Thank you for your time and effort in advance and please let me know if you have any questions or concerns.

Sincerely,

Jane Wright DDS

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