Anatomical Considerations for Miniplate-Anchored Maxillary Protraction in Children with Unilateral Cleft Lip and Palate

Jared Holloway
Marquette University

Follow this and additional works at: https://epublications.marquette.edu/theses_open

Part of the Dentistry Commons

Recommended Citation
https://epublications.marquette.edu/theses_open/606
ANATOMICAL CONSIDERATIONS FOR MINIPLATE-ANCHORED MAXILLARY PROTRACTION IN CHILDREN WITH UNILATERAL CLEFT LIP AND PALATE

by

Jared R. Holloway, D.M.D

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.

Milwaukee, Wisconsin
August 2020
Objective: The aim of this study was to explore the anatomical considerations of children with unilateral cleft lip and palate (UCLP) for the purpose of placing orthodontic miniplates for maxillary protraction.

Materials and Methods: Cone beam computed tomography (CBCT) images of 41 patients with UCLP (18 females and 23 males with a mean age of 9.8) and 36 (19 females and 17 males with a mean age of 9.9) age-matched controls were assessed in this retrospective study. Multiple linear measurements were taken to evaluate the bone thickness of the infrazygomatic crest region (IZCR), buccal alveolar bone, and inferior portion of the zygoma. In addition, the width of ten craniofacial and circummaxillary sutures were measured in the coronal, axial, and sagittal plane. Furthermore, the maturation level of the zygomaticomaxillary sutures (ZMS) were identified. Lastly, the volume of the maxillary sinuses was calculated. Statistical comparisons were made for each of the variables between the control and UCLP groups.

Results: There were no statistically significant differences of age and gender distributions between the groups. The greatest average bone thickness was found in the zygoma region in both groups, ranging from about 7 to 9 mm. The mean IZCR thickness did not exceed 3 mm in patients with UCLP. Analysis of the maxillary sinus revealed no significant differences between the two groups. The mean suture width of the right pterygomaxillary, left ZMS, and internasal sutures were larger in control group. The mean suture width of the right and left frontomaxillary, intermaxillary, left nasomaxillary and midpalatal sutures were larger in UCLP group. All patients were either at Stage A or Stage B of the maturation level of the ZMS and Stage B made up the majority in both groups.

Conclusions: Patients with UCLP have sufficient bone thickness to accommodate miniscrews for fixation of miniplates in the zygoma but may not have enough in the infrazygomatic crest. The maxillary sinus volumes were similar between UCLP and the control group, but there were some significant differences in suture width between the control and UCLP group.
ACKNOWLEDGEMENTS

Jared R. Holloway, D.M.D

I would like to give a shout out to all those who have contributed to the ideas, energy, and labor that have been put into this project and thesis paper. Special thanks to my wife, children and God who have been beside me throughout this entire journey. I would like to extend my deepest gratitude to the team at Shriner’s Hospital for Children in Chicago, especially Dr. Pravin Patel, Dr. Chad Purnell, and Dr. Linping Zhao. I am also grateful for the staff and doctors at Youngquist Kennedy Orthodontics who provided countless resources and time that rendered this study possible.

I am extremely grateful to Dr. David Forbes and Dr. Mark Runge who connected me to Shiner’s Hospital for Children and their insights on orofacial clefts. Many thanks to Dr. Mary Cimrmancic and the Department of Radiology at Marquette for their help in enhancing my knowledge of anatomy and 3-D technology. I also wish to thank Dolphin Imaging & Management Solutions and KLS Martin Group for their insights into imaging and utilizing skeletal anchorage. Special thanks to Dr. Ahmed Ghoenima who provided assistance with suture identification.

Thanks also to my Program Director, Dr. Dawei Liu, and the faculty and staff in the Department of Orthodontics at Marquette who provided encouragement and much needed guidance. I would also like to recognize the help of Dr. Maharaj Singh who gave life to the numbers and added meaning to the project with his insight on statistical analyses.
# TABLE OF CONTENTS

ACKNOWLEDGEMENTS .................................................................................................................. i

LIST OF TABLES ............................................................................................................................ iv

LIST OF FIGURES ........................................................................................................................... v

LIST OF ABBREVIATIONS ................................................................................................................. vii

REVIEW OF THE LITERATURE ...................................................................................................... 1

  Prevalence of Retrognathic Maxilla in Cleft and Non-Cleft Populations ....................... 1
  History of Protraction Therapy and Growth Modification of the Maxilla .................... 2
  Mechanobiology of Craniofacial Sutures ......................................................................... 3
  Use of Suture Maturation Index to Predict Success of Protraction .............................. 4
  Maxillary Sinus Volume in Patients with Unilateral Cleft Lip and Palate ................. 6
  Bone Quantity of the Infrazygomatic Crest Area in Adolescents with Unilateral Cleft
    Lip and Palate Compared to a Non-Cleft Population ................................................. 8

MATERIALS AND METHODS ....................................................................................................... 11

  Study Subjects ............................................................................................................................... 11
  Imaging and Scans ......................................................................................................................... 12
  Software Analysis and Landmark Identification ................................................................. 13
  Craniofacial and Circummaxillary Suture Width ............................................................... 15
  Statistical Analysis ...................................................................................................................... 15
  Zygomaticomaxillary Suture Maturation Stage ................................................................. 22
  Bone Thickness of Zygoma ........................................................................................................ 23
  Bone Thickness of Infrazygomatic Crest and Buccal Alveolar Bone ......................... 25
  Distance from Inferior Border of Zygoma to Buccal Alveolar Crest ......................... 27
  Maxillary Sinus Volume .............................................................................................................. 28
RESULTS .................................................................................................................. 30

Intra-rater Reliability and Statistical Analysis .......................................................... 30
Comparison of Groups by Age and Gender ............................................................... 30
Distribution of the Maturational Stages of the Zygomaticomaxillary Suture ........ 30
Comparison of Suture Width .................................................................................. 32
............................................................................................................................... 33
Comparison of Bone Thickness and Maxillary Sinus Volume ............................... 34
............................................................................................................................... 35
Comparison of the ZM-AC Distance ..................................................................... 37
DISCUSSION ........................................................................................................ 38

Patient Selection Criteria ...................................................................................... 38
Sufficient Bone Thickness and the Length of Miniscrews ...................................... 38
Comparing Images with Different Voxel Sizes ...................................................... 40
Comparing the Maxillary Sinus Volume ................................................................. 40
Predicting a Favorable Response to Protraction .................................................... 41
Can Protraction Replace Maxillary Jaw Surgery? .................................................. 42

CONCLUSIONS ...................................................................................................... 43

BIBLIOGRAPHY ...................................................................................................... 44
LIST OF TABLES

Table 1. Gender distribution by group .........................................................14

Table 2. Summary of the mean age by group .............................................14

Table 3. Demographics of the sample by age category ...............................14

Table 4. Summary of ICC for measurements .............................................31

Table 5. Distribution of Maturation Stages by Gender ...............................31

Table 6. Average suture width along the midline for Control and UCLP ........33

Table 7. Average suture width on the right side for Control and UCLP ........33

Table 8. Average suture width on the left side for Control and UCLP ..........33

Table 9. Average volume of the maxillary sinus on the right and left side of Control and UCLP .................................................................35

Table 10. Average bone thickness of the zygoma on the right and left side of Control and UCLP .................................................................35

Table 11. Average thickness of buccal bone represented by Z1 and Z2 landmarks on the right and left side of Control and UCLP ........................36

Table 12. Average thickness of infrrazygomatic crest bone represented by landmark Z3 on the right and left side of Control and UCLP ...............36

Table 13. Average distance from the buccal alveolar bone to the inferior border of the zygoma on the left and right side of Control and UCLP ..........37
LIST OF FIGURES

Figure 1. Frontal view of a skull with labels of the frontomaxillary, frontonasal, frontozygomatic, internasal, intermaxillary and nasomaxillary sutures ..................16

Figure 2. Inferior view of a skull with labels of the pterygomaxillary, midpalatal, intermaxillary, zygomaticomaxillary and zygomaticotemporal sutures .....................16

Figure 3. Lateral view of a skull with labels of the pterygomaxillary, zygomaticotemporal, zygomaticomaxillary, nasomaxillary, frontonasal and frontozygomatic sutures ..................................................................................................................17

Figure 4. Image sections of the nasal region: A, the frontonasal suture; ..................18

Figure 5. Image sections of the zygomatic region: A, the frontozygomatic suture; B, the zygomaticomaxillary suture; C, the zygomaticotemporal suture .......................19

Figure 6. A, Image section of the pterygomaxillary suture ..................................19

Figure 7. Image sections of the maxillary region: A, example of the intermaxillary suture in Control; B, example of the intermaxillary suture in UCLP; C, example of the midpalatal suture in Control; D, example of the midpalatal gap/suture in UCLP ........................................................................................................................................20

Figure 8. Identification of landmarks for the midpalatal suture: A, horizontal cursor bisecting central fossae; B, horizontal cursor at the most inferior portion of the hard palate; .................................................................................................................................21

Figure 9. Visualization of the zygomaticomaxillary suture: .....................................22

Figure 10. Micro view of the ZMS: A, Example of Stage A with a thin, uniform high-density line; B, Example of Stage B with a thicker high-density line .............22

Figure 11. View of the landmarks for measurements in the zygoma region: A, frontal view of the landmarks on both sides of the skull; B, lateral view of the landmarks on the right side of the skull .....................................................................................................................23

Figure 12. Identification of the initial reference point for the zygoma measurements: A, the most anterior and inferior portion of the zygoma; B, the inferior border of the zygoma, indicated by the blue horizontal cursor; C, sagittal view to mark both anterior and inferior border ................................................................................................................24

Figure 13. The measurements of the inferior zygoma: A, the first and second landmarks for measuring the zygoma in the coronal plane; B, Example of how the
thickness was measured perpendicular to the bone, as indicated by the green lines; C, sagittal view of first landmark

Figure 14. Measurements of the IZC and buccal bone: A, identification of the superior and inferior limits and the three associated measurements as indicated by the orange dots; B, the three measurements (Z1-Z3)

Figure 15. Orientation of the measurements in the anterior-posterior limit: A, sagittal view of cuts (green vertical lines); B, axial view of the cuts (green lines)

Figure 16. Measurement of the ZM-AC distance with the superior and inferior limits identified by the green dots.

Figure 17. Clipping boundaries and seed points for measurement of the maxillary sinus: A, coronal plane; B, sagittal plane; C, axial plane
LIST OF ABBREVIATIONS

BAMP: bone anchored maxillary protraction
CBCT: cone-beam computed tomography
DB: distobuccal
FM: facemask
FMS: frontomaxillary suture
FZS: frontozygomatic suture
ICC: interclass correlation coefficient
INS: internasal suture
IMS: intermaxillary suture
IR: intraradicular
IZCR: infrazygomatic crest region
MB: mesiobuccal
MPS: midpalatal suture
MSV: maxillary sinus volume
NMS: nasomaxillary suture
PTMS: pterygomaxillary suture
RME: rapid maxillary expansion
TADs: temporary anchorage devices
UCLP: unilateral cleft lip and palate
ZGB: zygoma bone
ZM-AC: zygoma to alveolar crest
ZMS: zygomaticomaxillary suture

ZMTS: zygomaticotemporal suture
PREVALENCE OF RETROGNATHIC MAXILLA IN CLEFT AND NON-CLEFT POPULATIONS

Modification at the skeletal level for correction of a deficient maxilla has been shown to be achievable through orthopedic treatment for patients with or without UCLP, and skeletal anchorage is a more recent approach to addressing maxillary retrognathia in a class III malocclusion. Patients with cleft lip and palate often present with an underdeveloped maxilla in a transverse, anterior-posterior, and vertical plane of space (Oberoi et al., 2008). The prevalence of maxillary retrognathia in the cleft population varies across studies, but one study done in England reported a 34% incidence of maxillary retrognathism in a group of 200 patients (Foster, 1962). Another group led by Voshol et al. considered the need for a patient to have a Le Fort 1 surgery as an indirect method to determine frequency of maxillary retrognathia and found the range for patients with a cleft varied from 0% up to 69.6%. Their group also reviewed the literature for data on patients with unilateral cleft lip and palate (UCLP) and found the prevalence to be 33.7% (2012). In comparison to class III malocclusions in a non-cleft population, Ellis and McNamara reported a prevalence of maxillary retrusion in 62-67% of their Class III adult group (1984). Facemask (FM) therapy is the traditional orthopedic solution to address a retrognathic maxilla, and this modality has shown to provide forward displacement of the maxilla both with and without palatal expansion (Cordasco, 2014). Increased forward growth of not only the maxilla, but also the advancement of the midface can be achieved with use of class III elastics attached to the hooks of bone plates (De Clerk & Proffit, 2015). These mini plates, sometimes called bollard plates, are placed
in the maxilla and mandible, and have gained traction in the cleft population as an alternative for more skeletal correction with less dentoalveolar side effects (B. K. Cha & Ngan, 2011; Ren et al., 2019).

**History of Protraction Therapy and Growth Modification of the Maxilla**

Historically, protraction therapy has been used to influence growth modification in the cleft and non-cleft population with variable success, and skeletal anchorage has shown skeletal alterations with minimal dental compensations despite taking place at a later age when the majority of anterior-posterior growth in the maxilla is completed. Prior to facemask therapy, alteration of the innate facial growth pattern of the nasomaxillary complex to correct the class III malocclusion was seen as an unrealistic feat as reported by Vig and Mercado (2015), but success in both tooth-borne and skeletally anchored appliances are influenced by the timing of intervention (Borzabadi-Farahani et al., 2014; K.S. Cha, 2003; Franchi et al., 2004; Mandall et al., 2010; Tindlund, 1994). Impactful change in the transverse, anterior-posterior and vertical dimension of the maxilla is to some extent dependent on the time clock for each plane of space. Each facial plane has its own stage of maturation: transverse development is the first to cease, usually by early adolescence, then anterior-posterior growth, around late adolescence, followed by vertical growth which extends well into the third decade (Proffit et al., 2013, pp. 475-476). One of the great challenges associated with orthopedic therapy is the attempt to maximize skeletal effects while controlling the dental changes. When it comes to the treatment timing of anterior-posterior changes of the nasomaxillary complex, the greatest opportunity for true skeletal alteration significantly diminishes after age 8 (p. 482). Both
Baccetti in a non-cleft group and Tinlund in a cleft group found that greater forward movement of the maxilla was achieved using facemask therapy in their earlier treated groups. Baccetti reported an average age of about 6 for the early group and compared them to a later treated group that averaged about 10 years of age while Tinlund’s study group averaged 8 years old (Baccetti et al., 1988; Tinlund, 1994). These findings have been validated by many others (Kajiyama et al., 2004). However, bone anchored protraction typically takes place at a mean age of 12 to ensure proper bone support of temporary anchorage devices (TADs) and eruption of the mandibular canines (De Clerk & Profitt, 2015). Producing forward displacement of the maxilla by either method is influenced by the mechanobiology of craniofacial and circummaxillary sutures and their anatomical limitations.

Mechanobiology of Craniofacial Sutures

Stimulating sutural osteogenesis is at the heart of orthopedic changes within the upper face and maxilla, and protraction using skeletal anchorage has shown the ability to produce distraction of the circummaxillary sutures which influence resistance to movement and new bone formation (Nguyen et al., 2011). Opening of the sutures involves stretching the fibers within them, and animal studies have confirmed that these changes are associated with new bone deposition (Baccetti et al, 1988; Ito et al., 2014; Jackson et al., 1979). J.J. Mao described cranial and facial sutures as “soft connective-tissue articulations between mineralized bones in the skull (2002).” The sutures serve as growth sites and help to absorb the stresses of mechanical forces whether they are induced naturally or by orthopedic devices (Meikle, 2007; Mao et al., 2009; Rafferty &
Herring, 1999). The mechanical stress created from these forces results in a proliferation of sutural cells which occurs in tandem with increased sutural width (Mao, 2002).

Baccetti’s study found that a great deal of the forward displacement of the maxilla was a result of growth at the pterygomaxillary suture in response to expansion and protraction in their early-treatment group, but no significant modifications of this region nor the rest of the maxilla was found in their late-treatment group (1988). Nguyen’s study had an older group and used bone-anchored maxillary protraction (BAMP) therapy and they reported distraction at the zygomaticofrontal, zygomaticotemporal, zygomaticomaxillary, and transverse palatine sutures (2011). Similar findings were observed in patients with a complete unilateral cleft lip and palate by Jijin Ren’s group who also used BAMP therapy (2019). These and other studies have prompted the search for biomarkers that might reveal which patients will respond favorably to these treatment modalities and how the sutures influence success.

**Use of Suture Maturation Index to Predict Success of Protraction**

The maturation and development of circummaxillary sutures have been used as markers to predict a favorable orthopedic response to protraction treatment, but suture width as a biomarker has not been well studied, especially when comparing patients with a cleft to a non-cleft group. Angelieri and colleagues identified five stages of maturation of the zygomaticomaxillary suture (ZMS) in patients from age 5.6 to 58.4 years and ranked them from stage A to stage E using CBCT (2017a). Stage A was depicted as a uniform high-density sutural line with little to no interdigitation and the most advanced stage, Stage E, was described as complete fusion. These notations are important because
increased interdigitation or fusion of the circummaxillary sutures can oppose/resist orthopedic change. Finite analysis reveals the ZMSs to be a significant source of resistance in part due to the ZMS being the longest and thickest of the circummaxillary sutures. This system can be used as a way to assess the potential favorable response of the circummaxillary sutures to protraction forces. Angelieri et al. reported that no fusion was observed before age 10, each level of maturation was represented in the patients from age 10-15 years, and that after age 15 the majority of patients showed fusion of the ZMS (2017a). In a second study, this same group compared protraction using traditional facemask and expansion compared to BAMP. Both treatment modalities produced more favorable results for patients exhibiting the early maturational stages of the ZMS, with stage A and B demonstrating a far superior response. BAMP had better forward displacement of the maxilla, zygomas, and orbits overall despite having an older treatment group, however no significant differences in the amount of maxillary protraction were noted between the two therapies for patients at ZMS maturational stage C. One patient from the study exhibited a maturational stage E and demonstrated no sagittal or vertical movement of the maxilla, but some vertical movement of the zygoma (Angelieri, 2017b). The results suggest that both skeletal anchorage and tooth-borne protraction have a good correlation with ZMS maturation, however it did not report suture width nor the potential effect of widening them. In fact, there is very little information in the literature on the width of circummaxillary sutures and its potential impact on favorable outcomes. As mentioned previously other papers have cited widening/distraction of the sutures following protraction or expansion, but very few have reported an attempt to measure that change in terms of suture width. Ghoneima et al. used
CBCT to evaluate the impact of rapid maxillary expansion (RME) on the cranial and circummaxillary sutures and actually measured the pre and post-treatment widths of ten different sutures. Although long term results were not reported, he did find that significant widening of multiple sutures did occur following expansion. His methods could be used to evaluate pre and post-protraction for both patients with a cleft lip and palate and with no cleft. The use of Angelieri’s ZMS maturational stages and other potential biomarkers may render the treatment of an underdeveloped or mal-positioned maxilla to be more predictable in patients with a cleft lip and palate and no cleft when using either skeletal or tooth-borne options.

**Maxillary Sinus Volume in Patients with Unilateral Cleft Lip and Palate**

Variation in anatomy among adolescents, along with a tendency for sinusitis are important when considering placement of mini-implants near the sinus for maxillary skeletal anchorage (Kakish et al., 2000; Motoyoshi et al., 2015; Kravitz & Kusnoto, 2006). In addition to an underdeveloped maxilla, patients with cleft lip and palate may have a smaller maxillary sinus volume compared to non-cleft groups (Edur et al., 2015; Lopes de Rezende Barbosa et al., 2014). Evaluation of the maxillary sinus anatomy and the maxillary sinus volume (MSV) have been of particular interest for those treating patients with cleft lip and palate because sinus disease is relatively common for this group (Demirtas et al., 2018). Omer Demirtas’ group concluded from their study of adolescents that the MSV of patients with UCLP were significantly smaller than their non-cleft control group. They also reported that the sinus volume of the cleft side was smaller than the non-cleft side, but no differences were noted based on gender between the
two groups (2018). There is disagreement in the literature regarding MSV, as other authors have reported no differences between patients with cleft compared to noncleft groups (Hikisaka et al., 2013; Suzuki et al., 2000). Some of this may be attributed to the differences in age, methods of measurement, and sample size. To date, there are few studies that have reported the impact of protraction on maxillary sinus volume. Some conclude that it does not affect MSV, but others have data to support a significant increase following RME/FM treatment or distraction (Pamporakis et al., 2014; Ozbilen et al., 2019). Studies utilizing BAMP therapy or skeletal anchorage have not reported effects on MSV, but there is concern about perforation into the sinus during miniscrew placement. Mini plates are typically anchored into the infrazygomatic crest (IZC) of the maxilla during BAMP treatment, and this region is in close proximity with the lateral wall of the sinus. Xueting Jia et al. reported that 78.3% of the screws placed in the IZC of their patients penetrated the maxillary sinus (2018). Penetration can cause thickening of the sinus floor and compromise miniscrew stability as well as lead to issues of mucoceles or sinusitis (Kravitz & Kusnoto, 2006). Multiple studies found that the membrane of the maxillary sinus can be relatively accommodating to dental implants, but for the purpose of miniscrews Xueting recommends limiting the perforation to less than 1mm (Xueting et al., 2018; Zhong et al., 2013). Motoyoshi et al. concluded that in order “to avoid maxillary sinus perforation, the thickness of the sinus floor should be >6.0 mm or the screw length should be <6 mm (2015). The infrazygomatic crest and other regions near the maxillary sinus may be used as insertion sites for miniscrews, but careful evaluation of individual anatomy will be necessary to minimize complications.
Bone Quantity of the Infrazygomatic Crest Area in Adolescents with Unilateral Cleft Lip and Palate Compared to a Non-Cleft Population

The amount and quality of bone of the maxillary region in young individuals can be limited, but the infrazygomatic crest area within the cleft population and non-cleft groups may still provide adequate stability for skeletal anchorage. Ko et al. defines the infrazygomatic crest area as the “bony ridge along the curvature between the alveolar and zygomatic processes of the maxilla” (Ko et al., 2019, p. 2094). Many local host factors influence the primary stability of a miniscrew including, but not limited to, cortical bone thickness, bone mineral density, and the anatomy of surrounding structures (Pan et al., 2019; Cha et al., 2010; Park et al., 2006). Uribe et al. reported a failure rate of 21.8% for screws placed in the infrazygomatic crest in a group of adult patients, however there is very little information when it comes to adolescent patients and success in the same region (2015). Generally speaking, adolescents tend to have an increased failure rate compared to adults, which is thought to be influenced by a highly active bone metabolism and low maturation of bone (Motoyoshi et al., 2007; Topouzelis et al., 2012). There are currently no available studies comparing the cortical bone thickness between patients with cleft lip and palate and a non-cleft population. However, Farnsworth who studied a non-cleft group and Ko et al. who studied patients with UCLP had similar results when it came to the average cortical bone thickness for the infrazygomatic crest in adolescents (Farnsworth et al., 2011; Ko et al., 2019). The study carried out by Ko et al. looked at a larger region than Farnsworth so their average ranged from 0.94 – 1.49 mm whereas Farnsworth et al. reported a mean of 1.45 mm width. Ko et al. suggests there is enough thickness to provide primary stability, and Alrbata et al. agrees that a cortical bone
thickness of 1-2 mm may be enough for success with orthodontic miniscrews (Ko et al., 2019; Alrbata et al., 2014). It is worth noting however, that Ko et al. only found cancellous bone above and below the infrazygomatic crest. This will influence the length of screw that can be used, and the authors recommend a miniscrew of 4-5 mm for the purpose of supporting a miniplate that is 2 mm thick (2019).

Miniscrews for the purpose of miniplate fixation are commonly 5mm in length, based on the bollard plates of Hugo De Clerk, and although they can be utilized within the infrazygomatic crest, various anatomical factors can influence the overall bone thickness (De Clerk et al., 2009; Cha et al., 2010). Patients with a pneumatized maxillary sinus, long molar root length, severe buccolingual inclination of the roots, developing tooth buds, and a short maxillary alveolar process can diminish the available space for a miniscrew in the infrazygomatic crest (Santos et al., 2017). Limited data exists for total bone depth or thickness of the infrazygomatic crest in adolescents. Lee et al. evaluated a group of class III growing patients and discovered that the superior and lateral portions of the zygomatic process of the maxilla had the thickest region of total bone (2013). The median bone thickness ranged from 1.1 – 5 mm and the highest end of that spectrum comes from the zygomatic bone itself. It is also important to keep in mind that the method of measurement and miniscrew insertion can impact the amount of available bone as described by Murugesan et al. and others (Liou et al., 2007; Murugesan et al., 2019).

Baumgaertal and Hans measured adult skulls and used the root apices of the first molar as his anterior-posterior and initial vertical reference. He observed that bone thickness of the infrazygomatic crest generally became smaller as measurements moved superior to the root apices and that the region of the buccal furcation had thicker bone compared to the
mesiobuccal and distobuccal regions (2009). Individual variability plays a large role in the use of skeletal anchorage in adolescents, and both patients with cleft lip and palate and those without will benefit from additional research.
MATERIALS AND METHODS

Study Subjects

Approval for this study was obtained from the Institutional Review Board at Marquette University. The protocol also received institutional approval from Shriner’s Hospital for Children in Chicago as part of a registry of craniofacial patients. CBCT images of 77 children were previously obtained as a part of routine care and were reviewed and analyzed as part of this retrospective study. The control population was designated as Control and consisted of 36 non-cleft orthodontic patients (17 females, 19 males). The age of the control subjects ranged from 6-13 years with a mean age of 9.9 years. The second population was made up of 41 non-syndromic UCLP subjects (18 females, 23 males). The age of the cleft population ranged from 7-13 years with a mean age of 9.8 years and was designated as UCLP. A summary of the breakdown can be found in Table 1-3. The scans of the control group came from a private orthodontic office in Wisconsin, USA and the scans of subjects with UCLP came from Shriner’s Hospitals for Children in Chicago, USA. Exclusion criteria were patients with syndromes, known treatment with maxillary expansion, impaction of maxillary posterior teeth, and any subjects who had a transpalatal appliance (i.e. TPA, expander, etc.) at the time of the scan. All three Classes of occlusion based on Angle’s classification system were represented in this subject pool, however it was not tracked for the purposes of this study.
Imaging and Scans

The cone-beam computed tomography (CBCT) machine utilized for our control population was the i-CAT FLX V17 (Kavo, Brea, California). For patients 8 years and younger, scans were made at 90 kVp, 0.6mm voxel size, and 3mA with an exposure time of 2 seconds. Parameters included 16cm x 13cm field of view (FOV) and 99.2 mGycm². For patients 9 years and older, scans were made at 120 kVp, 0.3mm voxel size, and 5mA with an exposure time of 2 seconds. These parameters also included 16cm x 13cm FOV and 349.4 mGycm². Six of the scans within the control population were smaller and did not permit a complete evaluation of the frontonasal and nasomaxillary suture. The scans consisted of patients undergoing a comprehensive exam for orthodontic treatment. We were unable to determine if patients had had previous expansion or orthodontic treatment due to limited records.

The CBCT machine utilized for our patient population at Shriner’s Hospital was the i-CAT FLX V17 (Kavo, Brea, California) and the i-CAT Next Gen 17-19 (Kavo, Brea, California). Scans were made at 120 kVp, 0.3mm voxel size, and 5mA with an exposure time of 7.4 seconds. Parameters included 23cm x 17cm FOV and 877.6 mGycm². All images were taken prior to the patient’s anticipated alveolar bone graft. Some patients were in the middle of orthodontic treatment, as evidenced by the presence of braces in the scan. Orthodontic records were not accessible because orthodontic care was provided off site.
Software Analysis and Landmark Identification

Dolphin 3D Premium software (version 11.95, Dolphin Imaging and Management Solutions, Chatswoth, CA, USA) was used to analyze all of the CBCT scans. Data were exported in DICOM format into Dolphin Imaging software and oriented based on the protocol utilized by Cevidanes et al. (2009). Although the Anterior Nasal Spine (ANS) was absent or deviated for most patients with UCLP, the midsagittal plane could be defined by identification of nasion and basion landmarks. Two observers, an orthodontic resident and third-year dental student, were calibrated for use of Dolphin 3D imaging by a Biomedical Engineer at Shriner’s Hospital for Children in Chicago and a representative of Dolphin Imaging and Management Solutions. Dr. Ahmed Ghoneima, Program Chair of the Department of Orthodontics at Hamdan Bin Mohammed College of Dental Medicine, was consulted through a video conference to confirm landmarks and suture identification using CBCT imaging. Special anatomical considerations relevant to patients with cleft lip and palate were reviewed with orthodontists and surgeons associated with the Cleft Lip and Palate team at Shriner’s Hospital for Children in Chicago. Further training and review of anatomy was done by labeling sutures on a dry skull. Both observers worked independently for relevant measurements and data collection. The third-year dental student evaluated the maxillary sinus volumes. The orthodontic resident evaluated the circummaxillary sutures, zygomaticomaxillary suture maturation, and bone thickness of the buccal bone, infrayzygomatic crest regions and zygomas. Each of the measurements were done using the default settings presented in the Dolphin 3D software to minimize the influence of contrast or brightness adjustments.
Table 1. Gender distribution by group

<table>
<thead>
<tr>
<th>Gender</th>
<th>Group</th>
<th>Control</th>
<th>UCLP</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td></td>
<td>19</td>
<td>18</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>52.78%</td>
<td>43.90%</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td></td>
<td>17</td>
<td>23</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>47.22%</td>
<td>56.10%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>36</td>
<td>41</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46.75%</td>
<td>53.25%</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Summary of the mean age by group

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of Subjects</th>
<th>Mean Age</th>
<th>Std Dev</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>36</td>
<td>9.86</td>
<td>1.81</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>UCLP</td>
<td>41</td>
<td>9.8</td>
<td>1.52</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>77</td>
<td>9.83</td>
<td>1.65</td>
<td>6</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 3. Demographics of the sample by age category

<table>
<thead>
<tr>
<th>Age Category</th>
<th>Group</th>
<th>Control</th>
<th>UCLP</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>10+</td>
<td></td>
<td>21</td>
<td>22</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>58.33%</td>
<td>53.66%</td>
<td></td>
</tr>
<tr>
<td>6 to 9</td>
<td></td>
<td>15</td>
<td>19</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>41.67%</td>
<td>46.34%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>36</td>
<td>41</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46.75%</td>
<td>53.25%</td>
<td></td>
</tr>
</tbody>
</table>
Craniofacial and Circummaxillary Suture Width

The width of ten craniofacial and circummaxillary sutures were evaluated based on the methods of Ghoneima et al. (2011). A schematic representation of the sutures used in this study can be viewed in Figures 1-3. At each suture of interest, the largest region of lucency was measured on either an axial, coronal, or sagittal view (Figures 1-4). The sutures included in the study were the frontonasal, frontomaxillary, frontozygomatic, zygomaticotemporal, zygomaticomaxillary, internasal, nasomaxillary, intermaxillary, pterygomaxillary, and midpalatal. Bilateral structures were measured on both the left and right sides. Patients with a cleft palate are essentially missing a midpalatal suture, however, for comparison purposes this gap will be referred to as a suture.

Statistical Analysis

Statistics were calculated for Control and UCLP by using paired $t$ tests to detect significant differences in bone thickness, suture width, maxillary sinus volume, linear measurements of the IZCR, and the maturation of the ZMS sutures. Statistical analyses were done using IBM SPSS (version 26), SAS (version 9.4) as well as a one-way ANOVA analysis with Bonferroni post-hoc test for multiple comparisons. The alpha value was set to .05 for each comparison.
Figure 1. Inferior view of a skull with labels of the pterygomaxillary, midpalatal, intermaxillary, zygomaticomaxillary and zygomaticotemporal sutures

Figure 2. Frontal view of a skull with labels of the frontomaxillary, frontonasal, frontozygomatic, nasomaxillary, internasal, and intermaxillary sutures
Figure 3. Lateral view of a skull with labels of the pterygomaxillary, zygomaticotemporal, zygomaticomaxillary, nasomaxillary, frontonasal and frontozygomatic sutures
Figure 4. Image sections of the nasal region: A, the frontonasal suture; B, the frontomaxillary suture; C, the internasal suture; D, the nasomaxillary suture
Figure 5. Image sections of the zygomatic region: A, the frontozygomatic suture; B, the zygomaticomaxillary suture; C, the zygomaticotemporal suture

Figure 6. A, Image section of the pterygomaxillary suture
Figure 7. Image sections of the maxillary region: A, example of the intermaxillary suture in Control; B, example of the intermaxillary suture in UCLP; C, example of the midpalatal suture in Control; D, example of the midpalatal gap/suture in UCLP
The midpalatal suture was measured at the first molars, and the process is depicted in Figure 5. A reference line was drawn to bisect both first molars at the central fossa in the axial view. Whenever the reference line did not cross both central fossae, the more anterior molar was used. At the same time a separate vertical reference was used in the coronal view by placing the horizontal cursor at the most inferior portion of the hard palate, or the most inferior portion of the nasal floor. After moving through the various axial slices to this vertical position a measurement was made along the bisecting line in the axial view.

Figure 8. Identification of landmarks for the midpalatal suture: A, horizontal cursor bisecting central fossae; B, horizontal cursor at the most inferior portion of the hard palate; C, measurement of the midpalatal suture in UCLP
Zygomaticomaxillary Suture Maturation Stage

Both the left and right zygomaticomaxillary sutures were visualized in the sagittal plane to determine the maturation stage of each patient based on the methods and protocols of Angelieri et al. (2017a). If two stages of maturation existed in the same patient, the more advanced stage of maturation was assigned. Each stage is based on the density of the sutural line as well as interdigitation (Figure 6 and 7).

![Figure 9. Visualization of the zygomaticomaxillary suture: A, macro view in sagittal plane; B, micro view of the ZMS indicated by arrows](image)

![Figure 10. Micro view of the ZMS: A, Example of Stage A with a thin, uniform high-density line; B, Example of Stage B with a thicker high-density line](image)
Bone Thickness of Zygoma

Bone thickness was analyzed at two locations on the lateral aspect of both the right and left zygomatic bones. The initial reference point for the first measurement was determined in the sagittal plane by identifying the most inferior and anterior point of the zygomaticomaxillary buttress with a vertical cursor. Next, the inferior border of the zygoma was marked in the coronal slice using a horizontal cursor. Then, in the coronal plane, the horizontal cursor was moved three millimeters superior to the inferior border of the zygoma and the first measurement was taken perpendicular to the bone. The second measurement is made by moving the same horizontal cursor in the coronal view an additional three millimeters superior, and then moving the vertical cursor in the sagittal plane three millimeters posterior. The measurements can be visualized in Figures 8-10.

Figure 11. View of the landmarks for measurements in the zygoma region: A, frontal view of the landmarks on both sides of the skull; B, lateral view of the landmarks on the right side of the skull
Figure 12. Identification of the initial reference point for the zygoma measurements: A, the most anterior and inferior portion of the zygoma; B, the inferior border of the zygoma, indicated by the blue horizontal cursor; C, sagittal view to mark both anterior and inferior border.

Figure 13. The measurements of the inferior zygoma: A, the first and second landmarks for measuring the zygoma in the coronal plane; B, Example of how the thickness was measured perpendicular to the bone, as indicated by the green lines; C, sagittal view of first landmark.
**Bone Thickness of Infrazygomatic Crest and Buccal Alveolar Bone**

Measurements of the infrazygomatic crest region (IZCR) and buccal alveolar bone was based on the protocols of Ko et al. (2019) and Baumgaertel and Hans (2009). For the purposes of this study, the infrazygomatic crest and buccal alveolar bone were evaluated superior to the first molar. Three separate measurements were done in three-millimeter increments. The first two measurements were below the apices of the roots and were considered to be part of the buccal alveolar bone. Measurements superior to the roots and inferior to the zygomatic bone were considered to be part of the infrazygomatic crest (Liou et al., 2005). The first reference point was made after designating the inferior border of the zygoma as the superior limit, and the buccal crestal bone of the alveolar process as the inferior limit. A vertical line was drawn from the superior limit to the inferior limit, and the first measurement was made at the halfway point between the two landmarks (Figure 11). Each subsequent measurement was made every three millimeters from the previous one and all were done perpendicular to the bone. The anterior-posterior landmarks were based on the roots of the first molar and correspond to the apex of the mesiobuccal (MB) root, distobuccal (DB) root, and interradicular (IR) space between the two buccal roots of the first molar. A horizontal cursor was placed to bisect the MB root, DB root, and IR space within the axial view so as to establish the section where the bone width would be evaluated in the coronal plane (Figure 12). The first two measurements (Z1 and Z2) correspond to the thickness of the buccal alveolar bone and the third measurement (Z3) correlates to the thickness of the infrazygomatic crest.
Figure 14. Measurements of the IZC and buccal bone: A, identification of the superior and inferior limits and the three associated measurements as indicated by the orange dots; B, the three measurements (Z1-Z3)

Figure 15. Orientation of the measurements in the anterior-posterior limit: A, sagittal view of cuts (green vertical lines); B, axial view of the cuts (green lines)
Distance from Inferior Border of Zygoma to Buccal Alveolar Crest

In order to appreciate the zone of opportunity within the IZCR, a vertical frame of reference was indicated. Other authors have used the occlusal plane as their reference to measure the vertical window available for TADs in the IZCR (Vilella et al., 2018). However, the measurement applied to this study used the buccal crestal bone of the maxillary alveolar process as the inferior reference plane. This method was used to promote the use of skeletal landmarks rather than dental landmarks in order to minimize variation due to dental anatomy. The distance from the inferior border of the zygoma to the crestal bone of the maxillary alveolar process was recorded for both the right and left side (Figure 13). This was done at the anterior-posterior position of the central fossa of the first maxillary molar. This measurement in the subsequent tables and references will be abbreviated as ZM-AC (zygoma to alveolar crest).

Figure 16. Measurement of the ZM-AC distance with the superior and inferior limits identified by the green dots.
Maxillary Sinus Volume

The right and left maxillary sinus volumes were measured separately using the “Sinus/Airway Analysis” tool in Dolphin 3D Premium software (version 11.95, Dolphin Imaging and Management Solutions, Chatswoth, CA, USA). Airway sensitivity was performed using the “Quick” option and the threshold value was set to 40. Starting in the sagittal view, the largest cross-sectional area was located by scrolling through the various slices. A clipping boundary was then drawn around the border of the maxillary sinus. Once the boundary was established, a seed point was placed within the largest cross-sectional area (Figure 14). All slices within the sagittal plane were evaluated from medial to lateral in order to confirm the boundary did not exclude any areas of the maxillary sinus. Throughout the various slices, more seed points were added as necessary to regions not illuminated by the software. This entire procedure was repeated in the axial and coronal views and then the sinus volume was calculated by selecting the “Update Airway” option.
Figure 17. Clipping boundaries and seed points for measurement of the maxillary sinus: A, coronal plane; B, sagittal plane; C, axial plane
RESULTS

**Intra-rater Reliability and Statistical Analysis**

The intraclass correlation coefficient (ICC) showed moderate reliability with an overall mean of 0.862-0.972 and is shown in further detail in Table 4. Measurements were carried out in three separate intervals that were about two weeks apart.

**Comparison of Groups by Age and Gender**

Due to the lack of statistical significance and the small sample size, additional analyses based on age and gender were not done ($P = 0.33$).

**Distribution of the Maturational Stages of the Zygomaticomaxillary Suture**

The breakdown of the maturational stages is displayed in Table 5. None of the subjects had complete fusion of the ZMS, and only Stages A and B were visible across both groups. The majority of the subjects were in Stage B (72.7%). Due to the small sample size, comparison of other variables based on maturation stage was not done. As described by Angelieri et al., Stage A consisted of a thin “high-density sutural line, with little to no interdigitation” and Stage B entailed a “thicker scalloped high-density line with some interdigitation” (2017a, p. 88).
Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type C intraclass correlation coefficients using a consistency definition. The between-measure variance is excluded from the denominator variance.

b. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.
Comparison of Suture Width

Comparisons between Control and UCLP revealed that there were statistically significant differences in the mean suture width for the right pterygomaxillary, left and right frontomaxillary, left zygomaticomaxillary, left nasomaxillary, internasal, intermaxillary, and midpalatal sutures. All other sutures did not show statistically significant differences. These comparisons were made using paired $t$-tests and are listed in Tables 6-8. An ANOVA analysis confirmed these findings and attributed the significant differences to patients with a cleft on the left side (data not included). We are unable to explain this finding, and it may be that a larger sample size would even out the distribution.

The UCLP group had a larger mean width for the intermaxillary, midpalatal, left and right frontomaxillary, and left nasomaxillary suture region. The control group had a larger mean width for the right pterygomaxillary, internasal and left zygomaticomaxillary suture region.
Table 6. Average suture width along the midline for Control and UCLP

<table>
<thead>
<tr>
<th>Suture</th>
<th>Group</th>
<th>Mean</th>
<th>Std Dev</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontonasal width (mm)</td>
<td>Control</td>
<td>1</td>
<td>0.4</td>
<td>0.6823</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>1</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Internasal width (mm)</td>
<td>Control</td>
<td>0.7</td>
<td>0.3</td>
<td>0.0164*</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>0.6</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Nasomaxillary width Right (mm)</td>
<td>Control</td>
<td>0.6</td>
<td>0.1</td>
<td>0.183</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>0.6</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Nasomaxillary width Left (mm)</td>
<td>Control</td>
<td>0.5</td>
<td>0.1</td>
<td>0.001*</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>0.6</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Intermaxillary width (mm)</td>
<td>Control</td>
<td>0.5</td>
<td>0.4</td>
<td>0.0016*</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>0.8</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Midpalatal width (mm)</td>
<td>Control</td>
<td>0.9</td>
<td>0.4</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>11.6</td>
<td>10.2</td>
<td></td>
</tr>
</tbody>
</table>

*statistically significant values are marked in yellow

Table 7. Average suture width on the right side for Control and UCLP

<table>
<thead>
<tr>
<th>Suture</th>
<th>Group</th>
<th>Mean</th>
<th>Std Dev</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zygomaticomaxillary width Right (mm)</td>
<td>Control</td>
<td>0.7825</td>
<td>0.225</td>
<td>0.2267</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>0.7244</td>
<td>0.1934</td>
<td></td>
</tr>
<tr>
<td>Frontozygomatic width Right (mm)</td>
<td>Control</td>
<td>1.1355</td>
<td>0.3382</td>
<td>0.3814</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>1.0707</td>
<td>0.2848</td>
<td></td>
</tr>
<tr>
<td>Pterygomaxillary width Right (mm)</td>
<td>Control</td>
<td>1.0389</td>
<td>0.3908</td>
<td>0.0124*</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>0.8439</td>
<td>0.245</td>
<td></td>
</tr>
<tr>
<td>Zygomaticotemporal width Right (mm)</td>
<td>Control</td>
<td>0.725</td>
<td>0.2842</td>
<td>0.2962</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>0.8756</td>
<td>0.8616</td>
<td></td>
</tr>
<tr>
<td>Frontomaxillary width Right (mm)</td>
<td>Control</td>
<td>0.8125</td>
<td>0.1947</td>
<td>0.0348*</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>0.939</td>
<td>0.3049</td>
<td></td>
</tr>
</tbody>
</table>

*statistically significant values are marked in yellow

Table 8. Average suture width on the left side for Control and UCLP

<table>
<thead>
<tr>
<th>Suture</th>
<th>Group</th>
<th>Mean</th>
<th>Std Dev</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zygomaticomaxillary width Left (mm)</td>
<td>1</td>
<td>0.7694</td>
<td>0.1954</td>
<td>0.0283*</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.6756</td>
<td>0.1729</td>
<td></td>
</tr>
<tr>
<td>Frontozygomatic width Left (mm)</td>
<td>1</td>
<td>1.0839</td>
<td>0.2806</td>
<td>0.9805</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.0854</td>
<td>0.2351</td>
<td></td>
</tr>
<tr>
<td>Pterygomaxillary width Left (mm)</td>
<td>1</td>
<td>0.9111</td>
<td>0.3031</td>
<td>0.2489</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.839</td>
<td>0.2407</td>
<td></td>
</tr>
<tr>
<td>Zygomaticotemporal width Left (mm)</td>
<td>1</td>
<td>0.6861</td>
<td>0.2086</td>
<td>0.5578</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.7146</td>
<td>0.2151</td>
<td></td>
</tr>
<tr>
<td>Frontomaxillary width Left (mm)</td>
<td>1</td>
<td>0.7313</td>
<td>0.2442</td>
<td>0.0246*</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.8659</td>
<td>0.2516</td>
<td></td>
</tr>
</tbody>
</table>

*statistically significant values are marked in yellow
Comparison of Bone Thickness and Maxillary Sinus Volume

Evaluation of the measurements within the zygomas revealed no significant differences between Control and UCLP (Table 10). There were also no significant differences in the maxillary sinus volume between the two groups nor between the cleft and non-cleft sides (Table 9). However, there were statistically significant differences in some regions of the buccal bone and infrazygomatic crest between the two groups which are summarized in Tables 11 and 12. Analyses indicated that the average bone thickness of the IZCR, as signified by measurement Z3, above the mesiobuccal root of the first molar was greater in Control on both the left and right side. In addition, the control group also showed thicker bone at the infrazygomatic crest and buccal bone at measurement Z2 above the interradicular space, on the left side. However, UCLP showed thicker buccal alveolar bone at measurement Z1 of the mesiobuccal root for both the left and right side.
Table 10. Average volume of the maxillary sinus on the right and left side of Control and UCLP

<table>
<thead>
<tr>
<th>Region</th>
<th>Group</th>
<th>Mean</th>
<th>Std Dev</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary Sinus Volume_Right (mm$^3$)</td>
<td>Control</td>
<td>7938</td>
<td>3495</td>
<td>0.5394</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>8440.2</td>
<td>3626.1</td>
<td></td>
</tr>
<tr>
<td>Maxillary Sinus Volume_Left (mm$^3$)</td>
<td>Control</td>
<td>8367.7</td>
<td>3596.9</td>
<td>0.9123</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>8450.9</td>
<td>3005.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 9. Average bone thickness of the zygoma on the right and left side of Control and UCLP

<table>
<thead>
<tr>
<th>Region</th>
<th>Group</th>
<th>Mean</th>
<th>Std Dev</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zygoma_Measurement 1_Right (mm)</td>
<td>Control</td>
<td>7.9444</td>
<td>2.3318</td>
<td>0.1522</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>7.2317</td>
<td>1.9917</td>
<td></td>
</tr>
<tr>
<td>Zygoma_Measurement 2_Right (mm)</td>
<td>Control</td>
<td>9.3167</td>
<td>2.4563</td>
<td>0.1529</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>8.3634</td>
<td>3.2222</td>
<td></td>
</tr>
<tr>
<td>Zygoma_Measurement 1_Left (mm)</td>
<td>Control</td>
<td>7.9611</td>
<td>1.984</td>
<td>0.0598</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>7.1512</td>
<td>1.7348</td>
<td></td>
</tr>
<tr>
<td>Zygoma_Measurement 2_Left (mm)</td>
<td>Control</td>
<td>8.8917</td>
<td>1.9048</td>
<td>0.5342</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>8.5512</td>
<td>2.8367</td>
<td></td>
</tr>
</tbody>
</table>
Table 11. Average thickness of buccal bone represented by Z1 and Z2 landmarks on the right and left side of Control and UCLP

<table>
<thead>
<tr>
<th>Region of First Molar</th>
<th>Group</th>
<th>Mean</th>
<th>Std Dev</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesiobuccal Root Z1 Right (mm)</td>
<td>Control</td>
<td>3.905</td>
<td>2.1058</td>
<td>0.1716</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>3.7512</td>
<td>2.3096</td>
<td></td>
</tr>
<tr>
<td>Mesiobuccal Root Z2 Right (mm)</td>
<td>Control</td>
<td>4.3972</td>
<td>1.703</td>
<td>0.4347</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>3.7512</td>
<td>2.3096</td>
<td></td>
</tr>
<tr>
<td>Interradicular Space Z1 Right (mm)</td>
<td>Control</td>
<td>5.8389</td>
<td>4.0111</td>
<td>0.6599</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>5.2146</td>
<td>2.9378</td>
<td></td>
</tr>
<tr>
<td>Interradicular Space Z2 Right (mm)</td>
<td>Control</td>
<td>4.1222</td>
<td>1.693</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>3.922</td>
<td>2.2086</td>
<td></td>
</tr>
<tr>
<td>Distobuccal Root Z1 Right (mm)</td>
<td>Control</td>
<td>3.5333</td>
<td>1.3638</td>
<td>0.7398</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>3.4073</td>
<td>1.9331</td>
<td></td>
</tr>
<tr>
<td>Distobuccal Root Z2 Right (mm)</td>
<td>Control</td>
<td>3.4028</td>
<td>1.3629</td>
<td>0.8413</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>3.3244</td>
<td>2.031</td>
<td></td>
</tr>
<tr>
<td>Mesiobuccal Root Z1 Left (mm)</td>
<td>Control</td>
<td>2.7139</td>
<td>1.0114</td>
<td>0.0052*</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>3.7732</td>
<td>2.0742</td>
<td></td>
</tr>
<tr>
<td>Mesiobuccal Root Z2 Left (mm)</td>
<td>Control</td>
<td>3.9972</td>
<td>1.6795</td>
<td>0.174</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>3.4268</td>
<td>1.9338</td>
<td></td>
</tr>
<tr>
<td>Interradicular Space Z1 Left (mm)</td>
<td>Control</td>
<td>4.9556</td>
<td>2.9172</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>5.3098</td>
<td>2.6747</td>
<td></td>
</tr>
<tr>
<td>Interradicular Space Z2 Left (mm)</td>
<td>Control</td>
<td>3.9778</td>
<td>1.8296</td>
<td>0.018*</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>3.0024</td>
<td>1.708</td>
<td></td>
</tr>
<tr>
<td>Distobuccal Root Z1 Left (mm)</td>
<td>Control</td>
<td>3.5944</td>
<td>1.4207</td>
<td>0.2938</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>3.2098</td>
<td>1.73</td>
<td></td>
</tr>
<tr>
<td>Distobuccal Root Z2 Left (mm)</td>
<td>Control</td>
<td>3.2111</td>
<td>1.5657</td>
<td>0.3008</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>2.8512</td>
<td>1.4637</td>
<td></td>
</tr>
</tbody>
</table>

*statistically significant values are marked in yellow

Table 12. Average thickness of infrrazygomatic crest bone represented by landmark Z3 on the right and left side of Control and UCLP

<table>
<thead>
<tr>
<th>Region of First Molar</th>
<th>Group</th>
<th>Mean</th>
<th>Std Dev</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesiobuccal Root Z3 Right (mm)</td>
<td>Control</td>
<td>3.8</td>
<td>1.9296</td>
<td>0.0462*</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>2.9073</td>
<td>1.9259</td>
<td></td>
</tr>
<tr>
<td>Interradicular Space Z3 Right (mm)</td>
<td>Control</td>
<td>3.1889</td>
<td>1.6855</td>
<td>0.2423</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>2.7171</td>
<td>1.8094</td>
<td></td>
</tr>
<tr>
<td>Distobuccal Root Z3 Right (mm)</td>
<td>Control</td>
<td>2.5083</td>
<td>1.3795</td>
<td>0.7631</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>2.3976</td>
<td>1.7757</td>
<td></td>
</tr>
<tr>
<td>Mesiobuccal Root Z3 Left (mm)</td>
<td>Control</td>
<td>3.6139</td>
<td>1.8418</td>
<td>0.0114*</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>2.5175</td>
<td>1.8383</td>
<td></td>
</tr>
<tr>
<td>Interradicular Space Z3 Left (mm)</td>
<td>Control</td>
<td>2.9611</td>
<td>1.4885</td>
<td>0.0231*</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>2.24</td>
<td>1.2178</td>
<td></td>
</tr>
<tr>
<td>Distobuccal Root Z3 Left (mm)</td>
<td>Control</td>
<td>2.0743</td>
<td>1.1589</td>
<td>0.8198</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>2.1341</td>
<td>1.1197</td>
<td></td>
</tr>
</tbody>
</table>

*statistically significant values are marked in yellow
Comparison of the ZM-AC Distance

There were no significant differences between Control and UCLP when comparing the mean distance from the crest of the buccal alveolar bone to the inferior border of the zygoma. A summary of the mean values is shown in Table 13 and were measured along the axis of the central fossa of the maxillary first molar. In both groups a clinician would have, on average, a vertical window of about 14 mm before getting into the zygomatic bone.

<table>
<thead>
<tr>
<th>Region</th>
<th>Group</th>
<th>Mean</th>
<th>Std Dev</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zygoma to Alveolar Crest _ Right (mm)</td>
<td>Control</td>
<td>14.1917</td>
<td>2.9738</td>
<td>0.6182</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>14.561</td>
<td>3.44</td>
<td></td>
</tr>
<tr>
<td>Zygoma to Alveolar Crest _ Left (mm)</td>
<td>Control</td>
<td>13.7056</td>
<td>2.8693</td>
<td>0.0942</td>
</tr>
<tr>
<td></td>
<td>UCLP</td>
<td>14.9293</td>
<td>3.3949</td>
<td></td>
</tr>
</tbody>
</table>
DISCUSSION

**Patient Selection Criteria**

Patients that undergo protraction therapy are traditionally adolescents, and patients with UCLP are evaluated for alveolar bone grafting around this same time interval. This overlap provides a unique opportunity to evaluate other anatomical sites in addition to the grafting site. There is a significant population of patients with bilateral cleft lip and palate (BCLP) at Shriner’s Hospital for Children in Chicago, however this study only focused on non-syndromic patients with UCLP to minimize variation. There are studies reporting that patients with BCLP respond less favorably to maxillary protraction compared to patients with UCLP, and new information may be obtained by applying these measurements to this group in the future (Ahn et al., 2012). In order to avoid other confounding factors that would interfere with measurements, patients with impacted posterior teeth or palatal appliances were excluded. Transverse discrepancies of the maxilla are frequent in patients with UCLP, and many potential scans were not included due to the presence of an expander or a transpalatal appliance. The purpose of measuring the suture widths was to obtain a baseline study of what to expect in adolescents, and recent expansion could have inflated results for either group.

**Sufficient Bone Thickness and the Length of Miniscrews**

The traditional miniscrew utilized for orthodontic maxillary miniplates are 5 mm in length, and although screw length has not been strongly correlated with stability, it can impact surrounding structures or lead to further complications (De Clerk et al., 2009;
Baumgaertel & Hans, 2009). Assuming that the miniplate is 2 mm thick, the amount of bone needed to accommodate the rest of the screw is at least 3 mm (Ko et al., 2019). Based on these parameters, adequate bone thickness in patients with UCLP may not be present. Initially, this study began with an evaluation of bone thickness above first premolar and second molar in addition to the first molar. However, due to limited time and resources the study was limited to the bone in the first molar region. The results of this study revealed that the mean bone thickness of the infrazygomatic crest, as designated by measurement Z3, was less than 3 mm for UCLP in each of the three measured regions above the first molar. However, both groups had less than 3 mm thickness in the infrazygomatic crest above the distobuccal root. These findings are summarized in Table 12. In general bone thickness tended to become thinner the more distal the measurement, in part due to the developing tooth buds of the second or third molars which can still be very high in younger patients. If one is looking for skeletal anchorage in the buccal bone, on average, the bone thickness in patients with UCLP was 3 mm or more in all regions except for measurement Z2 at the distobuccal root (Table 11).

Given the average limited bone thickness in patients with UCLP within the IZCR reported in this study, the zygoma may be a key alternative for BAMP therapy. The lowest measured value of the zygomatic region in UCLP was 3.4 mm, but the mean thickness ranged from 7.15 – 8.55 mm which would be more than enough bone thickness for a 5 mm miniscrew. Nevertheless, individual variability must be taken into account, and three-dimensional imaging can help in the decision process. All of these values
assume that the clinician is placing the screw perpendicular to the bone since angulation can influence bone thickness during screw placement (Villela et al., 2018).

**Comparing Images with Different Voxel Sizes**

One of the challenges of this study was finding two offices that routinely use CBCT imaging on their patients, and then using a software to compare them all together. The organizations that provided patient images for this study had their own protocols for scans and not all of them were done at the same voxel size. Every patient in UCLP received a scan with a voxel size of .3 mm, but six of the patients in Control had a scan with a voxel size of .6 mm. This represents a small portion of the control group but should be kept in mind when interpreting the results. There is also the potential for other sources of error such as partial volume averaging, artifacts, and the reported tendency for inaccurate bone height measurements in the maxillary region (Molen, 2010; Wood et al., 2013). However, Spin-Neto et al. found that even though higher voxel resolutions typically produce more accurate results, there are no standard protocols for a given diagnostic task. His systematic review also reported that multiple studies have shown no significant differences when comparing various voxel sizes for the purpose of measuring bone height and width (2012).

**Comparing the Maxillary Sinus Volume**

Our study found that there were no statistically significant differences in maxillary sinus volume between the two groups and between the cleft side versus the non-cleft side. These findings are consistent with those of Hikosaka et al. (2013). Other
studies have found that patients with UCLP have smaller volumes compared to non-cleft controls, and our results may differ due to variances in sample size and patient age (Erdur et al., 2015; Dermirtas et al., 2018).

**Predicting a Favorable Response to Protraction**

Maturation of the circummaxillary sutures has been linked to favorable growth modification of the maxilla, and the patients within this study all exhibited the early maturational stages of the zygomaticomaxillary sutures (Jackson et al., 1979). According to Angelieri et al. there are five maturation stages (Stage A-E) for the zygomaticomaxillary sutures, and the earliest stages (Stages A and B) have shown a more favorable response to protraction therapy than later stages which have increased interdigitation and fusion (2017b). The majority of Angelieri’s patient pool that were younger than 15 years were at maturational Stage B, and our results showed a similar pattern. There was a wider range of distribution of maturational stages in her study, and this may be attributed to individual variation or differences in training in the classification process (2017a). However, based on the work of Angelieri et al. all patients within this study would likely respond well to maxillary protraction therapy based on their early maturational stages of the ZMS. Currently there are no studies to support the use of suture width as a biomarker for predicting positive growth modification during protraction, but the results of this study may serve to initiate additional research that includes recording suture width before and after protraction. Patients with UCLP had larger suture widths in some of the measurements that were far removed from the cleft region, and we are unable to explain these differences. However, it is not surprising that
the intermaxillary and midpalatal sutures would be larger due to the presence of a cleft. It is possible that patients in the UCLP group had been previously treated with protraction therapy which could lead to increased widths of the other circummaxillary sutures (Baccetti et al., 1988). However, this seems unlikely because the statistically significant differences in suture width were not widespread throughout the circummaxillary region (Tables 6-8).

**Can Protraction Replace Maxillary Jaw Surgery?**

Based on the current literature, it remains unclear what impact BAMP therapy will have on reducing the amount of maxillary jaw surgeries in patients with UCLP (Garib et al., 2018). De Clerk et al. reported an average of 4 mm of maxillary advancement with BAMP therapy in non-cleft patients while Yatebe et al. reported an average of 1.66 mm in patients with UCLP and 2.37 mm in the non-cleft control group (De Clerk, 2009; Yatebe et al, 2017). Given the range of about 1 mm to 4 mm using BAMP therapy, it seems unlikely that it could be used to replace Le Fort I surgery or distraction osteogenesis which are reported to offer an average of 5.8 mm and 9.8 mm advancements (Daimaruya et al., 2010). Yatabe’s recent study suggests that patients with UCLP will respond similarly to non-cleft patients during BAMP therapy, however Nguyen et al. found that BAMP therapy can offer the additional benefit of forward movement of the zygoma and orbit which traditional facemask therapy and Le Fort I surgery do not provide (2017; 2011). Therefore, the use of skeletal anchorage for maxillary protraction will not necessarily be used to replace surgery, but rather to “complement the treatment outcome of a later jaw surgery that is likely already indicated” (Ren et al., 2019, p. 2440).
CONCLUSIONS

This study suggests that patients with UCLP have sufficient bone thickness to accommodate miniscrews for fixation of miniplates in the zygoma but may not have enough in the infrazygomatic crest. The maturational stages of the zygomaticomaxillary sutures in the cleft group were similar to the age-matched controls and consisted of Stages A and B. There were significant differences in suture width for the right pterygomaxillary, left and right frontomaxillary, left zygomaticomaxillary, left nasomaxillary, internasal, intermaxillary, and midpalatal sutures. All other circummaxillary sutures did not show statistically significant differences between the two groups. In addition, the maxillary sinus volume was similar between both groups.


Pediatric Otorhinolaryngology, 79(10), 1741-1744. https://doi.org/10.0116/j.ijporl.2015.08.003


