Three-Dimensional Evaluation of Facial Asymmetry in Patients with Hemifacial Microsomia

BY

MATTHEW STEVEN AHRENS

BS, University of Florida, 2007

DMD, University of Florida, 2010

THESIS

Submitted as partial fulfillment of the requirements for the degree of Masters of Science in Oral Sciences in the Graduate College of the University of Illinois at Chicago, 2013

Chicago, Illinois

Committee members:

T. Peter Tsay, DDS, MS, PhD, Advisor

Pravin Patel, MD, Department of Surgery

Linping Zhao, PhD, Department of Surgery

Grace Viana, Msc

ACKNOWLEDGEMENTS

I would like to thank my thesis committee, Dr. T. Peter Tsay, Dr. Pravin Patel, Dr. Linping Zhao and Grace Viana for their influential support and assistance throughout this process.

MSA

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

LIST OF ABBREVIATIONS

CBCT	Cone Beam Computed Tomography
CT	Computed Tomography
HFM	Hemifacial Microsomia
IRB	Institutional Review Board
PA	Posteroanterior

SUMMARY

The purpose of this study was to three-dimensionally evaluate facial asymmetry in individuals with Hemifacial Microsomia (HFM) using cone beam computed tomography (CBCT) images. Our primary objective was to use a previously established method for evaluating facial asymmetry using CBCT images and apply it to individuals with HFM. From this information we developed a new method for classifying Hemifacial Microsomia quantitatively.

The experimental group consisted of 16 individuals with diagnosed HFM that had initial CBCT scans taken in the Craniofacial Center at the University of Illinois at Chicago. Established cephalometric landmarks were indentified on the images and three-dimensional measurements were gathered. These measurements were then inserted into an equation to calculate the asymmetry index value for each landmark. Bilateral linear measurements of the mandibular body and ramus were compared. Finally, mandibular asymmetry values were compared to the corresponding Pruzansky-Kaban score.

All skeletal landmarks were found to have significantly larger asymmetry values when compared to unaffected controls. The mandibular body and ramus on the affected side were significantly smaller than the unaffected side. A positive correlation was found between the mandibular asymmetry value and Pruzansky-Kaban score. The study showed that individuals with HFM have asymmetry in the maxilla, mandibular body, and mandibular ramus. The study also introduced a new method for classifying HFM quantitatively.

1. INTRODUCTION

1.1. Background

Hemifacial microsomia is a congenital disorder with a unilateral deficiency of hard and soft tissues of the face. As a result of this unilateral deficiency, individuals will display a clearly discernible facial asymmetry. Hemifacial microsomia, or HFM, is the second most common facial anomaly and affects 1 in 5,000 births. The syndrome primarily involves defects of the first branchial arch such as: the temporomandibular joint, ramus, muscles of mastication, and ear. The disorder can also affect the facial nerve and facial muscles, second branchial arch structures. HFM can present with varying degrees of severity with the most severe form, Goldenhar's Syndrome, resulting in limbal dermoids, severe scoliosis, and underdevelopment of organs (Monahan et al., 2001).

Clinical diagnosis of the HFM patient traditionally involved a thorough assessment of the affected structures and any accompanying functional deficiencies. This has conventionally been accomplished in part through utilization of traditional two dimensional radiographs. The protocol utilized a panoramic radiograph for an overview of the skeletal structures and dentition. In patients with cleft palate an occlusal radiograph would also be needed. The anterior-posterior relationship of the maxilla, mandible, and cranial base would be evaluated with a lateral cephalometric radiograph. To evaluate the skeletal asymmetry from a frontal perspective, a posteroanterior cephalometric radiograph would be needed as well. To determine the extent of soft tissue deficiencies and malformations, facial photos would be utilized. The rigorous process of collecting all these records was not only time consuming but also limited in the scope of information that could be gained from each two-dimensional radiograph. These conventional x-rays were also prone to sources of error which made quantitative measurements unreliable.

The introduction of three-dimensional imaging such as CBCT has improved the clinician's ability to effectively evaluate the HFM patient's condition and plan the appropriate treatment. However, traditional diagnostic methods for HFM still are largely based on a two-dimensional approach. Also, current classification systems for HFM evaluate the condition based on descriptive categories. There currently is not a quantitative method for classifying the facial asymmetry present in these patients. A three-dimensional approach to evaluating and quantifying this condition should be developed and utilized.

1.2. Specific Aims

This study aims to address these issues by introducing a previously developed method of quantifying facial asymmetry and applying it to individuals with HFM. The purpose of this study is to three-dimensionally evaluate facial asymmetry in individuals with HFM using CBCT images. My objectives in this study are to: evaluate HFM in three-dimensions using an asymmetry index classification method, determine which mandibular segments are more affected, and compare this new classification approach to established descriptive classification methods.

1.3 Hypothesis

The experimental hypothesis is that individuals with HFM will have significantly more asymmetry in three-dimensions when compared to normal individuals. Secondly, there will be significant differences in the mandibular body and ramus lengths in subjects with HFM. Lastly, there will be a direct relationship between mandibular asymmetry values and the corresponding Pruzansky-Kaban score.

2. REVIEW OF LITERATURE

2.1 Three-Dimensional Technology

In the 1988 issue of the AJO-DO Grayson et al proposed combining the lateral and PA cephalometric radiographs to create a three-dimensional grid for evaluating patients with craniofacial abnormalities such as HFM (Grayson et al., 1988). This "three-dimensional cephalogram" was beneficial in that normative cephalometric values could be utilized, however, the process was very time consuming and did not incorporate soft tissue deficiencies. This approach also did not correct the problems commonly associated with two-dimensional lateral and PA cephalometric radiographs. With the implementation of computed tomography (CT), a three-dimensional image of both the soft and hard tissues can be captured in one image in a relatively short period of time. Not only can this three-dimensional image be used for initial diagnosis but it also allows for precise simulation of surgical treatment plans. The use of CT imaging for craniomaxillofacial surgical corrections has been advocated because of the three-dimensional nature of such deformities and use of minimally invasive surgical techniques such as distraction osteogenesis which demand precise preoperative measurements (Troulis et al., 2002). Also, by comparing pre and post CT images it allows for an accurate assessment of treatment outcomes.

Accurate identification of skeletal landmarks is crucial for diagnosis and treatment planning orthodontic cases. As previously mentioned traditional two-dimensional radiographic techniques consistently introduce sources of error in this process. The most common errors associated with these methods are magnification, projection, and identification error by the observer. Magnification error is caused by the divergent nature of the x-ray beams which give the appearance of objects being larger than their actual size. Projection errors are the result of a difference in magnification between the borders of a single object which lead to double images. Observer identification error has been reported extensively in the orthodontic literature for landmarks such as porion, condylion, orbitale, basion, gonion, anterior nasal spine, posterior nasal spine and lower incisor apex (Chien et al., 2009). Another common problem related to the capture of PA cephalometric films is rotation of the head within the cephalostat. One study compared two PA radiographs of the same subject with asymmetry and found that rotation of the head within the cephalostat of 5° resulted in an apparent reversal of the side in which asymmetry was present(Cook, 1980).

With the advent of three-dimensional imaging, claims have been made for an improved reliability in landmark identification. To determine the accuracy of these claims Chien et al designed a study comparing landmark identification in vivo between 2D lateral cephalometric and 3D CBCT images. Ten untreated cephalometric images with no asymmetry present and their corresponding CBCT images were compared. Six trained observers indentified 27 skeletal landmarks which were then measured from established reference planes. Results showed that 10 landmarks had error greater than 1mm when using 2D lateral cephalometric imaging. Based on previous studies 1mm of error in landmark identification was established as clinically significant. The study concluded that CBCT imaging allows for more accurate landmark identification and proves more useful for instances in which precise measurements are crucial (Chien et al., 2009). A similar study compared PA cephalometric, CBCT, and physical measurements of 10 dry skulls with no apparent asymmetry. The focus of this study was to determine the potential of CBCT for quantitative assessment of craniofacial dimensions compared to PA cephalometric images. To eliminate incorrect landmark identification as a source of error, metallic markers were placed on 17 skeletal landmarks from which 20 bilateral measurements were gathered. The results showed that all 10 apparently symmetric skulls had some extent of asymmetry although only two measurements overall had a difference that was considered clinically significant. The authors found close to perfect agreement between the CBCT and physical measurements, but poor agreement between PA ceph and physical measurements. It was also noted that the PA ceph accuracy would likely have been worse if not for the placement of metallic markers. The authors concluded that CBCT imaging has advantages over 2D imaging and is more capable of quantitatively assessing craniofacial morphology (Leonelli de Moraes et al., 2011).

The current trend in dentistry for three-dimensional imaging has shifted away from conventional CT scans and moved towards cone beam computed tomograms or CBCT. Since its introduction to dentistry in 1998 CBCT has gained popularity over CT because of its similar attributes but significantly less cost and radiation. The use of CBCT has especially become popular with the evaluation and treatment of craniofacial anomalies. The complex nature of these associated conditions demands accurate assessment and planning of both hard and soft tissues in three-dimensions, which CBCT imaging is able to provide.

2.2 Classification Systems of HFM

Due to the broad spectrum of clinical manifestation of HFM, classification systems have been developed to improve evaluating these patients. The first classification system for HFM was developed by Pruzansky and the primary focus was on the affected mandibular structures. Patients were categorized as: Grade I) have mandibles of normal shape but are reduced in size; Grade 2) have hypoplastic and malformed condyles, ramus, and TMJ; Grade 3) the mandible is severely hypoplastic and is completely lacking a condyle, coronoid process, and glenoid fossa (Pruzansky, 1969). Kaban modified this classification by subdividing Grade 2 based upon a difference in surgical approach: Grade 2a) have hypoplastic and malformed condyles, ramus, and TMJ but the TMJ spatial location is symmetrical to the unaffected side; Grade 2b) have a severely hypoplastic and malformed condyle and the TMJ is misplaced in relation to the unaffected side and also non-functional (Kaban et al., 1981). The SAT classification was developed with a focus on the involvement of Skeletal, Auricular, and soft-Tissue abnormalities (David et al., 1987). The most widely accepted classification system, OMENS, is similar to the SAT system by categorizing the affected structures using its pneumonic name. OMENS stands for the most commonly affected craniofacial structures in HFM: O (orbital), M (mandibular hypoplasia), E (ear deformity), N (nerve involvement), and S (soft tissue deficiency) (Vento et al., 1991). This system was expanded by adding OMENS-Plus (+) to include associated extracranial developmental defects in the central nervous and cardiac systems (Horgan et al., 1995).

A study in by Huisinga-Fischer et al modified the traditional classification systems of HFM by including cranial structures other than the mandible and using three-dimensional CT images to assess the affected structures. The author acknowledged the improved accuracy and detail from CT imaging which allowed for more precise assessment of the morphological features of HFM. However, this modified classification system was similar to the previous methods by its determination of severity based on a qualitative description of malformation present. This approach is useful for a determination of the affected structures but not for quantifying the extent of skeletal asymmetry present (Huisinga-Fischer et al., 2001).

2.3 Three-Dimensional Evaluation of Asymmetry

Traditionally in orthodontics lateral and frontal cephalometric images have been used to analyze the size, shape, and position of skeletal structures. Even with its inherent sources of error cephalometric analyses have proven useful to clinicians when diagnosing, planning, and assessing treatment outcomes. However, their usefulness is dependent upon a patient that has good facial symmetry. According to Profitt *et al* as much as 33% of patients with craniofacial anomalies have facial asymmetry (Profitt et al., 2007).

In a study by Gateno et al the effects of facial asymmetry on two-dimensional and three-dimensional cephalometric measurements were examined. A symmetrical three-dimensional model was designed as the control and 10 different asymmetric models were then created from the control model to duplicate different forms of maxillary and mandibular asymmetry. Each asymmetric model was then evaluated using seven commonly used cephalometric measurements on a 2D cephalometric projection and a 3D coordinate system, and these measurements were then compared to the control model. The results showed that 2D cephalometric measurements were distorted when assessing shape, size, and orientation. The results also showed that 3D cephalometric measurements were distorted when assessing position and orientation. The reason for this distortion in 3D cephalometric measurements is that some of the conventional cephalometric measurements are derived from 2D imaging and when a third dimension is added to the measurement it no longer meets its definition. Also, orientation measurements can be distorted when pitch, roll, and yaw changes are introduced to the object being measured and the 3D coordinate system is not adjusted accordingly. The study confirmed that facial asymmetry can affect the accuracy of both 2D and 3D cephalometric measurements, but only 3D measurement techniques can be adjusted to eliminate this inaccuracy (Gateno et al., 2011).

In order to accurately measure asymmetry in three-dimensions, reference planes must be established. Cevidanes et al sought out to establish this by measuring asymmetry using 3D shape analysis using two different reference plane techniques. The first technique was a landmark-based midsagittal reference plane. The second was an arbitrary midsagittal plane registered on the cranial base. Both were created from CBCT images of individuals with marked asymmetry. The reference planes were used to create hemimandibles which were then mirrored on top of each other. Jaw asymmetry was measured for each hemimandible using 3D distance maps between the mirrored structures. The results showed that both reference plane methods were acceptable in quantitatively measuring asymmetry. However, care must be taken in the landmark-based method as the accuracy of the plane depends on the availability and visibility of the landmarks (Cevidanes et al., 2011).

A recent case used CT imaging to evaluate a patient with marked mandibular asymmetry. The authors wanted to develop a method for identifying and evaluating the contributing factors of mandibular asymmetry. Initially the authors took a PA cephalometric radiograph which showed no discrepancy in ramus length. To further examine the causes of the asymmetry a CT scan was taken. Reference planes were then constructed to compare right and left skeletal measurements. The authors found that ramus length, ramal inclination, and body length were all significantly larger on the patient's right side. Their conclusion was that all of these factors contributed to the presence of mandibular asymmetry in this patient. The authors also concluded that the lack of discrepancy in ramus length initially observed in the PA ceph was the result of a difference in ramal inclination which could not be accounted for in the two-dimensional image. In closing the authors stated that quantitative measurements were crucial for treatment planning orthognathic surgery and 3D imaging provides a method for achieving this (Hwang et al., 2006).

As previously discussed the current HFM classification systems used to describe the mandibular deformities focuses on the TMJ and associated structures. In a recent study by Steinbacher et al the investigators sought to determine if HFM had a developmental effect on structures other than those associated with the TMJ. To evaluate the mandibular deformity in this manner 3D rendered volume segments were analyzed and then compared these results to the current Pruzansky classification system. This study was also one of the first to quantitatively analyze the mandibular deformity present in HFM. CBCT scans of subjects with HFM were split into hemimandibles and then each hemimandible was divided into dentate and proximal segments. The volume of each affected and unaffected hemimandible and segment were then compared to controls. As expected the results showed that the hemimandible and proximal segment of the affected side had decreased volume compared to the unaffected side. However, the dentate segment on the affected side also showed decreased volume. They also found that the unaffected side was smaller than the controls, which shows the bilateral nature of HFM. The study also established an inverse relationship between the volume of the dentate and proximal segments and an increasing Pruzansky score. This study confirmed that the mandibular deformity in HFM not only affects the proximal TMJ segment but the dentate segment as well (Steinbacher et al., 2011).

The use of CBCT has gained popularity in assessing and diagnosing individuals with craniofacial anomalies because of its accuracy and ability to evaluate the involved structures in three-dimensions. However, unlike traditional 2D cephalometric analyses there are no established 3D-based analysis methods. Katsumata et al developed a 3D analysis method to specifically diagnose and evaluate individuals with facial asymmetry. In order to develop a system for evaluating asymmetry the authors first had to establish baseline values from normal symmetric individuals. The control group consisted of 16 individuals ranging from teens to early thirties who had undergone CT imaging and had no discernible asymmetry present. Anatomical landmarks from accepted orthodontic cephalometric analyses were defined from axial CT slices. Next reference planes were established in the x, y, and z dimensions using anatomical landmarks. The landmark distance from each individual reference plane was then calculated.

These values for each landmark were then inserted into the following equation to determine a mean asymmetry index number for that landmark.

$$\text{Asymmetry Index} = \sqrt{(Rdx-Ldx)^2 + (Rdy-Ldy)^2 + (Rdz-Ldz)^2}$$

In the above equation (R) signifies right-side landmarks and (L) signifies left-side landmarks. An asymmetry index system based on ratios was used so that differences in size would not distort the findings. The mean asymmetry index for each landmark in control subjects was then displayed in a diagrammatic chart (Figure 1) in order to classify the degree of deformity in facial asymmetry patients (Katsumata et al., 2005). The follow-up study implemented this new approach in the evaluation 49 subjects who had craniofacial deformities and proved its effectiveness.

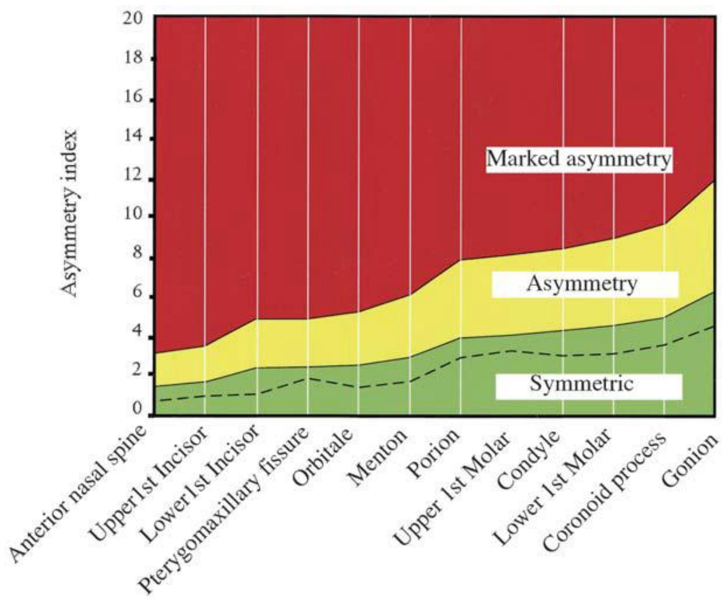

Figure 1. Mean asymmetry index values for symmetric individuals (Katsumata et al., 2005)

In summary, two-dimensional imaging is prone to inherent sources of error such as magnification, projection, and patient positioning. Research has also established that CBCT imaging is more accurate than two-dimensional imaging in landmark identification and measurement, especially in patients with craniofacial abnormalities. All of the previously discussed classification systems have proven to be effective only at giving a qualitative evaluation of the affected structures. These systems lack a method for quantifying the extent of malformation present initially and determining the changes that occurred through treatment. The goal of this study is to utilize CBCT imaging to develop a three-dimensional method for quantifying the degree and location of asymmetry present in individuals with HFM.

3. METHODOLOGY

3.1 Study Design

This is a retrospective study that will evaluate initial CBCT images of patients with HFM. A previously developed method by Katsumata et al to evaluate facial asymmetry will be applied to these CBCT images. Three-dimensional measurements will be gathered to evaluate the amount of asymmetry present. The data will then be compared to previously established norms to develop a method for classifying HFM. Also, the mandibular body and ramus lengths will be compared within the HFM group. Finally, mandibular asymmetry values will be compared to the Pruzasnky-Kaban classification system to determine if a relationship is present.

3.2 IRB Approval

A “Determination of Whether an Activity Represents Human Subjects Research” application was submitted to the UIC Office for the Protection of Research Subjects. The UIC OPRS determined on 4/19/12 that my study did not meet the definition of human subject research and therefore I was able to conduct my study without further submission to the IRB.

3.3 Methods and Materials

The experimental group consisted of 16 individuals with diagnosed HFM that had initial CBCT scans taken. The source of these images was the Craniofacial Center at the University of

Illinois at Chicago. The CBCT scans in this study are from an ICAT Next Generation by Imaging Sciences International, Inc., Hatfield, PA. The digital CBCT scans were de-identified by personnel from the Craniofacial Center and then given to the principal investigator. The inclusion criteria consisted of initial CBCT scans from male and female patients with diagnosed HFM. Patients with previous surgical treatment for HFM were excluded. Patients with bilateral HFM were excluded. Patients with other syndromes such as cleft-lip and palate were excluded.

The CBCT scans were measured and analyzed by the principal investigator using SimPlant Pro Crystal computer software. The CBCT scans were segmented to create a three-dimensional skeleton. This was done through the software using thresholds based on differences in the permeability of the tissues to the x-rays.

TABLE I

LIST OF SKELETAL LANDMARKS

Landmarks	Definition
Sella	center point within sella turcica
Nasion	junction of the nasal and frontal bones in the midline
Basion	odontoid process of the axis
Anterior nasal spine	most anterosuperior projection of the maxilla
Upper first incisor	crest of the alveolar ridge between the upper central incisors
Lower first incisor	crest of the alveolar ridge between the lower central incisors
Orbitale	most inferior point along infraorbital margin
Menton	lower border of the midmandibular suture
Upper first molar	center point within the pulp cavity of the upper first molar
Lower first molar	center point within the pulp cavity of the lower first molar
Condyle	most superior point on the head of the condyle
Coronoid process	most superior point on the coronoid process
Gonion	most inferior and posterior point along the angle of the mandible

The same 13 cephalometric skeletal landmarks used by Katsumata et al were identified using the 3D skeletal model and x-ray slices(Table 1). Skeletal landmark porion had to be omitted in our analysis because of the lack of an external auditory canal in some subjects. In individuals with severe hypoplasia of the condyle landmark condylion was placed on the remnant of the condyle at the most superior point. Three reference planes were then created using cranial base landmarks which are stable in individuals with HFM. First, the midsagittal plane was constructed through point's basion, sella, and nasion. Next, the axial plane was constructed through sella, nasion and perpendicular to the midsagittal plane. Finally, the coronal plane was constructed through basion and perpendicular to the midsagittal and axial planes. As performed by Katsumata et al only the following skeletal landmarks were used in the assessment of facial asymmetry: ANS, condyle, coronoid, gonion, lower first incisor, lower first molar, menton, orbitale, upper first incisor, and upper first molar. The distance from each landmark to the three reference planes was then measured to create the corresponding x,y,z measurements. Each landmarks x,y,z measurement was then individually inserted into the following equation(R=right, L=left):

$$\text{Asymmetry Index} = \sqrt{}(Rdx-Ldx)^2 +(Rdy-Ldy)^2 + (Rdz-Ldz)^2$$

The equation calculates the difference between the bilateral landmarks relative to each reference plane. For solitary midsagittal landmarks the asymmetry index only consisted of a dx value as there is no significance in the dy and dz values. The result is an asymmetry index number which corresponds to the skeletal asymmetry in three-dimensions for that landmark. The asymmetry index number for each landmark was then compared to previously established norms from subjects without clinically detectable asymmetry.

Next, the measurements for mandibular body and ramus lengths were calculated. The mandibular body was measured from menton to gonion and the mandibular ramus was measured from gonion to condylion. These values were then compared between the affected and unaffected sides of the mandible.

Finally, the asymmetry index values and Pruzansky-Kaban score for each individual were compared to determine if an association exists between the two classification methods. Each individual was given a score of I-III based on the established Pruzansky-Kaban classification system for HFM. Considering the Pruzansky-Kaban scoring is based only on the mandibular structures, the asymmetry index values of the mandibular landmarks were averaged to create a mandibular asymmetry index value for each individual.

3.4 Statistical Analysis

A one sample *t* test was used to determine statistical significance of the landmark asymmetry values of the HFM group to the control group. A paired samples *t* test was also used to compare the linear measurements of each mandibular segment. Finally, a Pearson coefficient of correlation was computed between the mandibular asymmetry index value and the corresponding Pruzansky-Kaban score.

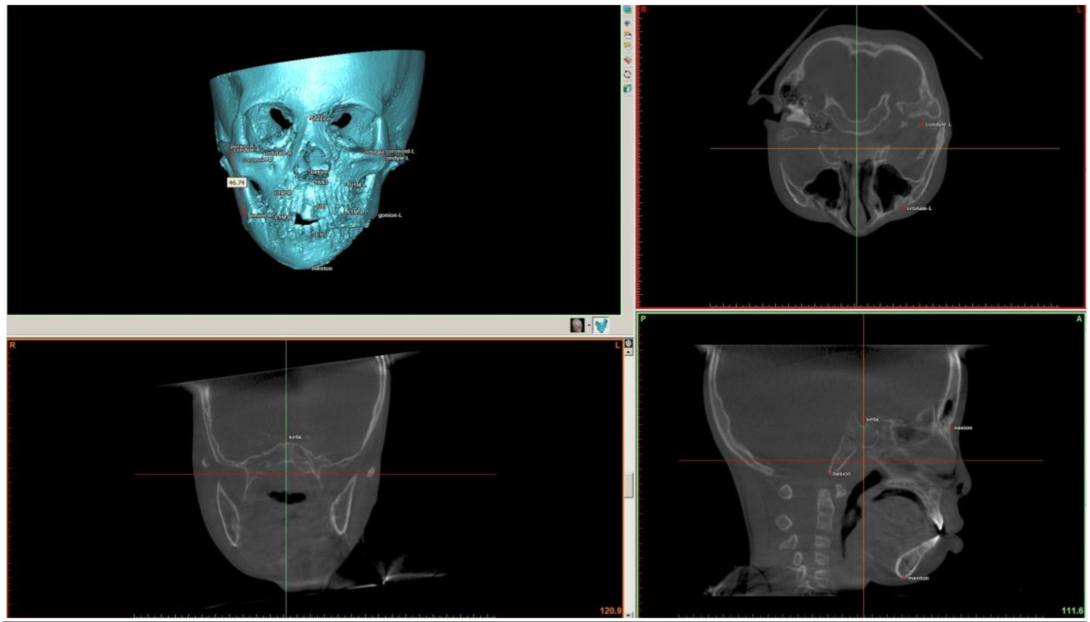

Figure 2. Example of 3D reconstructed model and x-ray slices from CBCT

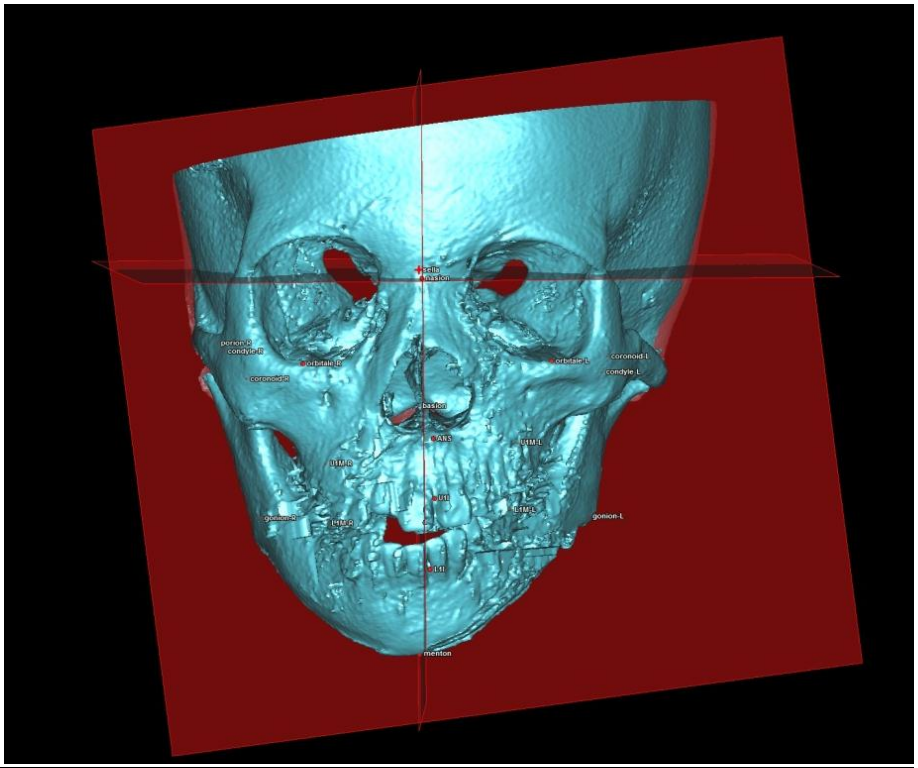

Figure 3. Example of constructed axial, coronal, and sagittal planes

4. RESULTS

4.1 Results

Table II shows the mean asymmetry index values of the skeletal landmarks in the experimental group of individuals with HFM as compared to symmetric individuals previously reported by Katsumata et al. All 10 landmarks were found to be significantly ($p<0.05$) larger in individuals with HFM. Figure 4 graphically displays these large differences in mean asymmetry values between the two groups.

TABLE II

MEAN ASYMMETRY INDEX FOR INDIVIDUAL LANDMARKS

Landmark	**HFM** **Mean + SD**	**Control** **Mean + SD**
ANS	2.19 ±1.55	0.8 ±0.7
Condyle	16.45 ±8.97	2.9 ±1.4
Coronoid	14.46 ±6.47	3.7 ±1.3
Gonion	19.09 ±16.09	4.6 ±1.7
L1I	6.25 ±4.42	1.2 ±1.2
L1M	18.05 ±10.27	3.2 ±1.4
Menton	10.69 ±7.86	1.8 ±1.1
Orbitale	6.08 ±2.32	1.7 ±0.8
U1I	3.15 ±2.05	0.9 ±0.8
U1M	12.50 ±5.00	3.1 ±1.0

Table III shows the mean ramus and body length between the affected and unaffected sides of the mandible. The ramus and body length of the affected side were found to be significantly ($p<0.001$) smaller than the unaffected side. Figure 5 graphically displays the difference in mean ramus and body length between the affected and unaffected sides.

TABLE III

MEAN MANDIBULAR BODY AND RAMUS LENGTHS

	Affected Hemimandible Mean + SD	**Unaffected Hemimandible Mean + SD**
Mean Ramus Length(mm)	39.03 ±8.07	52.67 ±7.29
Mean Body Length(mm)	70.51 ±10.09	79.00 ±7.43

To investigate if there was a statistically significant association between each subject's mandibular asymmetry index value and Pruzansky-Kaban score, a correlation was computed. The Pearson coefficient of correlation was computed and a statistically significant correlation of 0.64 ($p=0.008$) was found between the two methods. Figure 6 is a scatter plot which provides a visual display of the correlation. The direction of the correlation is positive, which means that as the mandibular index value increases the Pruzansky-Kaban score increases as well.

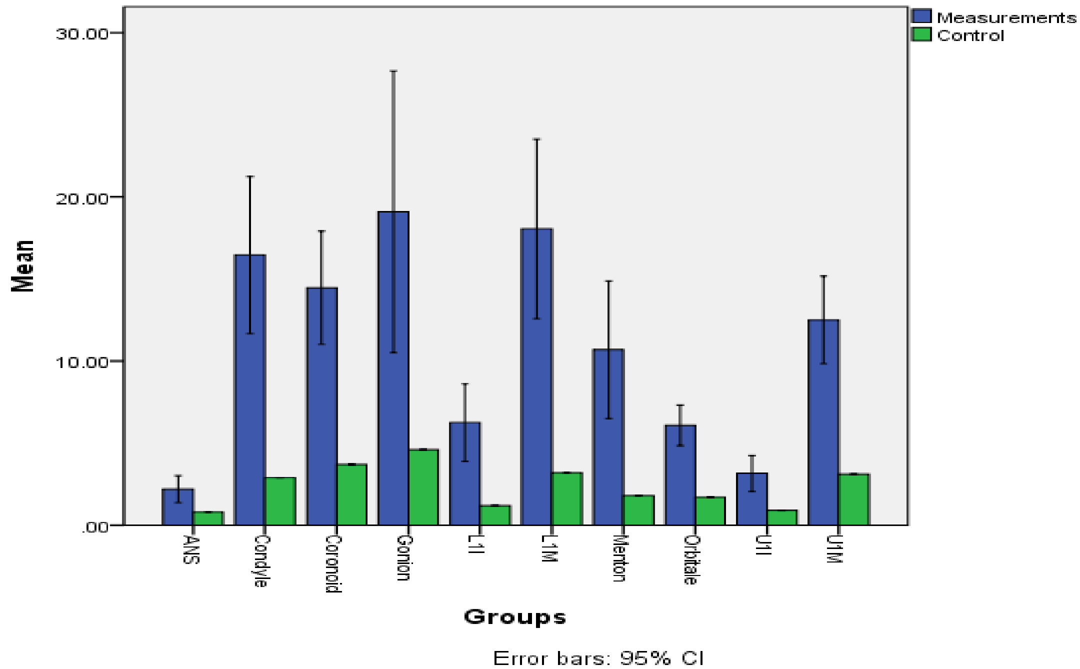

Figure 4. Graph of mean asymmetry index for each landmark

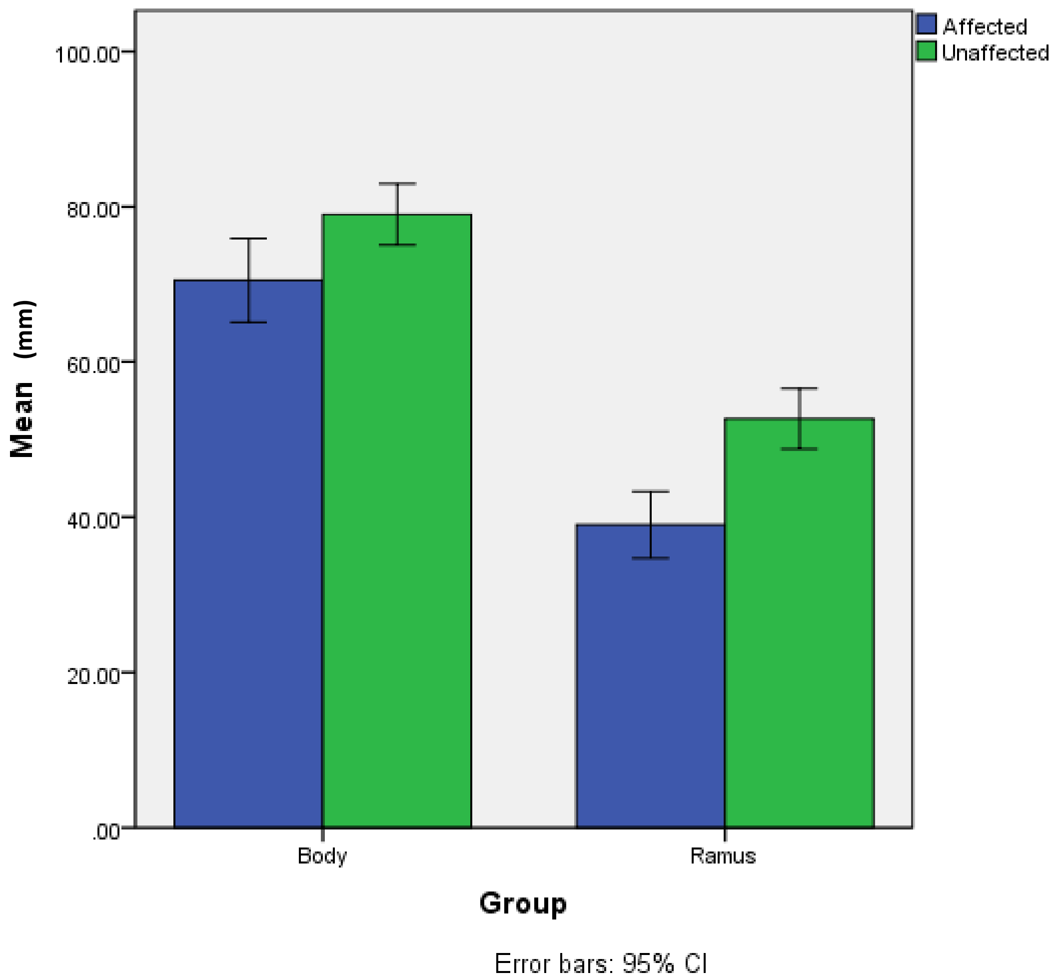

Figure 5. Graph of mean mandibular body and ramus lengths

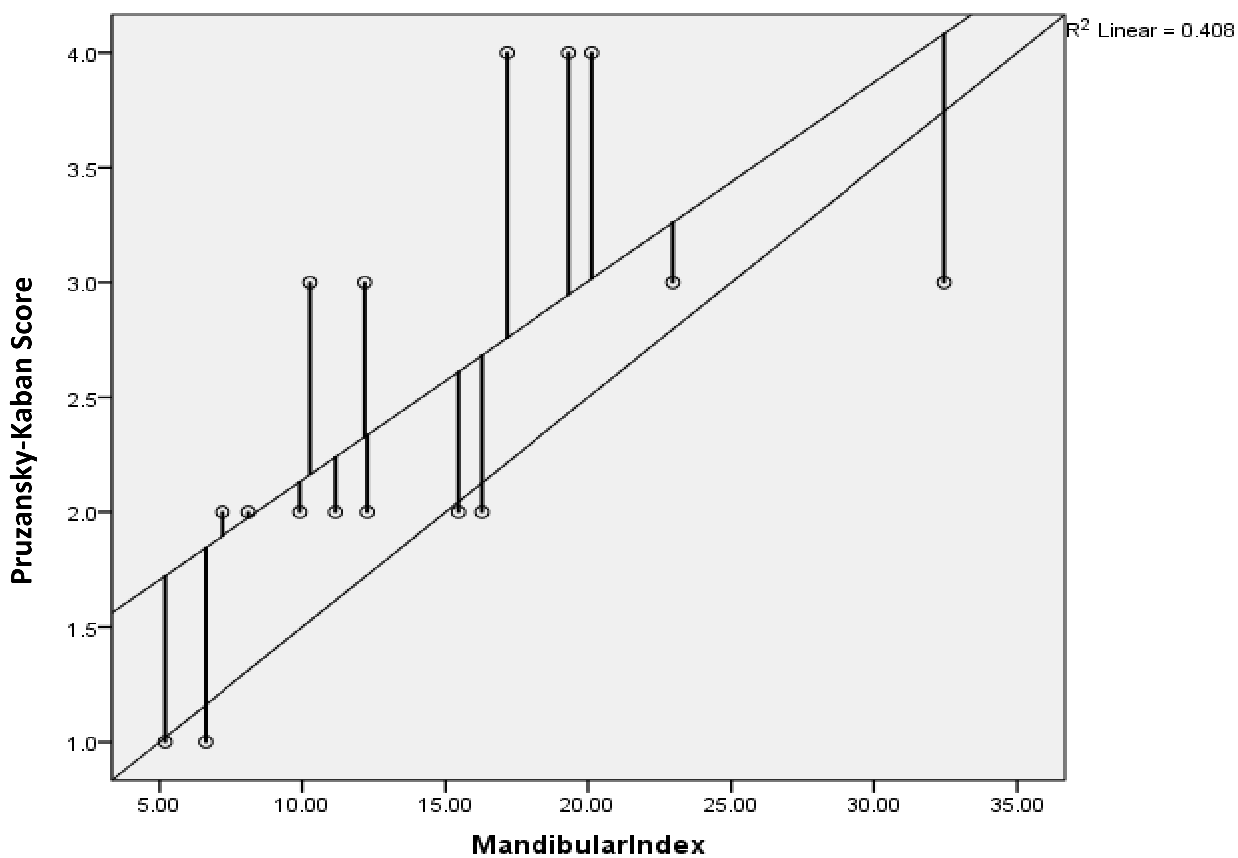

Figure 6. Scatter plot showing the correlation between mandibular asymmetry index and Pruzansky-Kaban score

5. DISCUSSION

5.1 Discussion

The use of three-dimensional CBCT imaging proved to be a highly effective diagnostic tool in the evaluation of individuals with HFM. The images allowed for accurate landmark identification which in turn resulted in precise measurements. The use of CBCT imaging also allowed for the construction of reference planes from which the skeletal asymmetry was assessed. Lastly, as noted from previous studies the margin for error in landmark identification is significantly less when using CBCT images as compared to two-dimensional imaging.

The implementation of the asymmetry index analysis developed by Katsumata et al demonstrated to be a useful method for evaluating and classifying HFM. In our experimental group all 10 skeletal landmarks were found to be significantly more asymmetric in comparison to the symmetric norms established by Katsumata et al. Although all 10 landmarks had an asymmetry index score that was significant; Figure 4 displays a trend of much larger asymmetry for bilateral landmarks which are located in the mandible (condyle, coronoid, gonion). All three of these landmarks are located within the ramal portion of the mandible. Therefore, within our HFM experimental group abnormal growth was more significant within the ramus than other craniofacial structures. This finding is also consistent with the focus of previous studies and the clinical presentation of the syndrome.

One of the strengths of this evaluation method was the use of a coordinate point system that takes into account asymmetry in all three dimensions by developing x, y, z reference planes. The use of CBCT imaging allowed for the construction of all three of these reference planes on one image. Many of the previous HFM studies using two-dimensional imaging had to construct these reference planes on two separate images which was a source for error. The landmarks that were used to construct these reference planes were chosen because of their location within structures of the cranium which are believed to be unaffected by HFM. This allowed for stable and reproducible reference planes that could be used to assess true asymmetry.

The practical application of this evaluation method for HFM is numerous. The ability to assess the location of affected structures and the extent of deformity is very valuable when diagnosing and treatment planning HFM. For the surgeon this method provides a highly accurate three-dimensional assessment which allows for precise planning of surgical movements. The quantitative data also enables the clinician to objectively evaluate the post treatment outcome.

The mandibular body and ramus lengths within our experimental group showed a significant decrease in length for both segments on the affected side when compared to the unaffected side (Table III, Figure3). However, when comparing the relative decrease in length between the ramus and body segments the ramus was more affected. This finding supports our asymmetry index measurements and coincides with the findings by Steinbacher et al. The accuracy of these particular linear measurements has also been found to be more reliable when measured on a three-dimensional image as compared to a two-dimensional cephalogram (Hwang et al., 2006). Determining the difference in these lengths between affected and unaffected sides would be beneficial when planning the surgical movements as well.

As previously mentioned one of the main objectives of this study was to develop a classification system for HFM that was based on quantitative measurements from three-dimensional imaging. To accomplish this objective the asymmetry index method developed by Katsumata et al was applied for this purpose. The analysis provided a quantitative assessment of asymmetry for each individual landmark. To determine the effectiveness of this new classification method it was compared to the gold-standard Pruzansky-Kaban classification method. The study showed a significant correlation between these two classification methods.

Additionally, a proposed method for classifying the overall asymmetry in each individual was developed. This was accomplished by averaging the landmark asymmetry values for each subject to create an overall asymmetry value for that individual. The scale developed for classifying this overall asymmetry was based upon the original classification from Katsumata et al. The baseline was established as the mean overall asymmetry (3.5) from the symmetric controls. Each classification group was then defined in intervals of 3.5. Table IV displays the groups that were developed. This proposed classification method was then applied to our experimental group and displayed visually in Figure 7. The strength of this classification method compared to previously established methods is the use of three-dimensional imaging to improve accuracy and objective classification based on measurements instead of qualitative assessment.

TABLE IV

PROPOSED HFM CLASSIFICATION GROUPS

Type 1	Type 2	Type 3	Type 4
3.5 - 7	7 – 10.5	10.5 - 14	> 14

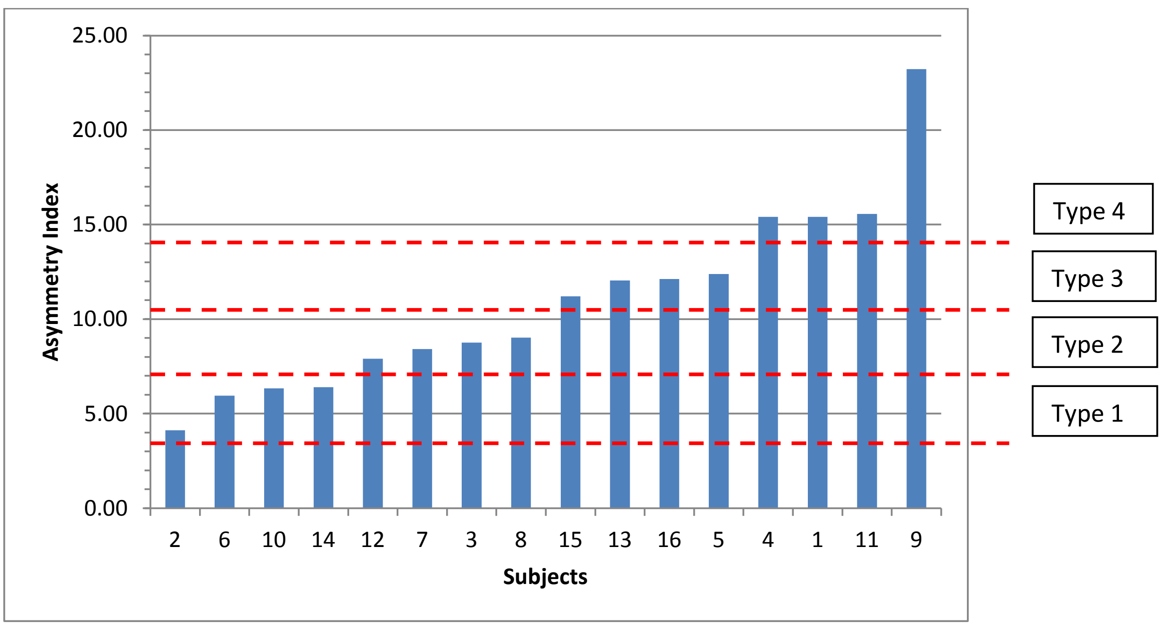

Figure 7. Proposed method for classifying HFM quantitatively

5.2 Limitations

A clear obstacle with this study was the limited number of individuals with untreated HFM that had CBCT imaging previously taken. As a result of the limited sample size it was not possible to eliminate possible contributing factors such as age and sex. Also, the comparison of linear measurements between affected and unaffected sides of the mandible could be distorted due to possible underdevelopment of the unaffected side relative to normal mandibles.

5.3 Further Research

Increasing the sample size in future research would improve the strength of the study. As previously mentioned controlling for variables such as age and sex could provide insight into their influence on HFM. Also, implementing this evaluation method with a longitudinal sample could help determine the progressive nature of the syndrome.

6. CONCLUSION

The results of this study have shown that individuals with HFM have asymmetry in the maxilla, mandibular body, and mandibular ramus. However, the mandibular ramus appears to be more affected than other regions. The study also introduced a new method for evaluating and classifying HFM using CBCT images. This new method corresponds with the growing trend for a three-dimensional approach to the diagnosis and treatment of craniofacial disorders.

LITERATURE CITED

Evidences, L., Alhadidi, A., Paniagua, B., Styner, M., Ludlow, J., Mol, A., Turvey, T., Proffit, W., Rossouw, P.: Three-dimensional quantification of mandibular asymmetry through cone-beam computerized tomography. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.* 2011; 111:757-770

Chien, P.C., Parks, E.T., Eraso, F., Hartsfield, J.K., Roberts, W.E., Ofner, S.: Comparison of reliability in anatomical landmark identification using two-dimensional digital cephalometrics and three-dimensional cone beam computed tomography in vivo. *Dentomaxillofacial Radiology* 2009; 38:262-273

Cook, J.T.: Asymmetry of the cranio-facial skeleton. *Br. J. Orthod.* 1980; 7:33-38

David, D.J., Mahatumarat, C., Cooter, R.D.: Hemifacial microsomia: a multisystem classification. *Plast. Reconstr. Surg.* 1987; 80(4):525-535

Figueroa, A.A., Pruzansky, S.: The external ear, mandible, and other components of hemifacial microsomia. *J. Max.-Fac. Surg.* 1982; 10:200-11

Gateno, J., Xia, J., Teichgraeber, J.: Effect of facial asymmetry on 2-dimensional and 3-dimensional cephalometric measurements. *J. Oral Maxillofac. Surg.* 2011; 69:655-662

Grayson, B.G., Cutting, C., Bookstein, F.L., Kim, H., McCarthy, J.G.: The three-dimensional cephalogram: Theory, technique, and clinical application. *Am. J. Orthod. Dentofacial Orthop.* 1988; 94:327-37

Horgan, J.E., Padwa, B.L., LaBrie, R.A., Mulliken, J.B.: OMENS-Plus: Analysis of Craniofacial and Extracranial Anomalies in Hemifacial Microsomia. *Cleft Palate-Craniofacial J.* 1995; 32:405-412

Huisinga-Fischer, C.E., Zonneveld, F.W., Vaandrager, J.M., Prahl-Anderson, B.P.: CT-based size and shape determination of the craniofacial skeleton: a new scoring system to assess bony deformities in hemifacial microsomia. *J. Cranio. Surg.* 2001; 12:87-94

Hwang, H.S., Hwang, C.H., Lee, K.H., Kang, B.C. Maxillofacial 3-dimensional image analysis for the diagnosis of facial asymmetry. *Am. J. Orthod. Dentofacial Orthop.* 2006; 130:779-785

Kaban, L.B., Mulliken, J.B., Murray, J.E.: Three-dimensional approach to analysis and treatment of hemifacial microsomia. *Cleft Palate J.* 1981; 18:90-99

Kapila, S., Conley, R., Harrell, W.: The current status of cone beam computed tomography imaging in orthodontics. *Dentomaxillofacial Radiology* 2011; 40:24-34

Katsumata, A., Fujishita, M., Maeda, M., Ariji, Y., Ariji, E., Langlais, R.: 3D-CT evaluation of facial asymmetry. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod*. 2005; 99:212-20

Leonelli de Moraes, M., Hollender, L., Chen, C., Moraes, L., Balducci, I.: Evaluating craniofacial asymmetry with digital cephalomertic images and cone-beam computed tomography. *Am. J. Orthod. Dentofacial Orthop.* 2011; 139:e523-e531

Maeda, M., Kastumata, A., Ariji, Y., Muramatsu, A., Yoshida, K., Goto, S., Kurita, K., Ariji, E.: 3D-CT evaluation of facial asymmetry in patients with maxillofacial deformities. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.* 2006; 102:382-90

Monahan, R., Seder, K., Patel, P., Alder, M., Grud, S., O'Gara, M.: Hemifacial Microsomia: Etiology, diagnosis, and treatment. *JADA* 2001; 132:1402-1407

Profitt, W.R., Fields, H.W., Sarver, D.M.: *Contemporary Orthodontics*. Mosby, 2007

Pruzansky, S.: Not all dwarfed mandibles are alike. *Birth Defects* 1969; 5:120-129

Steinbacher, D.M., Gougoutas, A., Bartlett, S.P.: An analysis of mandibular volume in hemifacial microsomia*. Plast. Reconstr. Surg.* 2011; 127:2407-12

Troulis, M.J., Everett, P., Seldin, E.B., Kaban, L.B.: Development of a three-dimensional treatment planning system based on computed tomographic data*. Int. J. Oral Maxillo. Surg.* 2002; 31:349-57

Vento, A.R., LaBrie, R.A., Mulliken, J.B.: The O.M.E.N.S. classification of hemifacial microsomia. *Cleft Palate-Craniofacial J.* 1991; 28:68-77

VITA

NAME: Matthew Steven Ahrens

EDUCATION: B.S., Nutritional Sciences, University of Florida, Gainesville, FL, 2007

D.M.D., University of Florida, Gainesville, FL, 2010

M.S., Oral Sciences, University of Illinois at Chicago, Chicago, IL, 2013

Certificate, Orthodontics, University of Illinois at Chicago, Chicago, IL, 2013

HONORS: Honors Combined BS / DMD acceptance, University of Florida, 2004

President's Honor Roll, University of Florida, 2003-2006

Anderson Scholar, University of Florida, 2005

Summer Research Fellowship, University of Florida, 2006

Cum Laude, University of Florida, 2007

Dean's List, University of Florida, 2007, 2008

Graduation Marshall, University of Florida, 2009

PROFESSIONAL

MEMBERSHIP: American Association of Orthodontics

American Dental Association

Chicago Dental Society

Illinois Society of Orthodontics