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Mandibular dental arch form determination from cone beam computed tomography at 4 levels

Bavar, Berokh

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Boston University
MANDIBULAR DENTAL ARCH FORM DETERMINATION FROM CONE BEAM COMPUTED TOMOGRAPHY AT 4 LEVELS

by

BEROKH BAVAR

B.S. McMaster University, 2008
D.M.D Boston University, 2013

Submitted in partial fulfillment of the requirements for the degree of
Master of Science in Dentistry
In the Department of Orthodontics & Dentofacial Orthopedics

2016
**APPROVED BY**

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<th>First Reader</th>
<th>Dr. David S. Briss, D.M.D., F.R.C.D.(C)</th>
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Acknowledgements:

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MANDIBLE DENTAL ARCH FORM DETERMINATION FROM CBCT AT 4 LEVELS

BEROKH BAVAR

Boston University, Henry M. Goldman School of Dental Medicine, 2016

Major Professor: David Briss, Professor of Orthodontics

ABSTRACT

Objectives: The objective of this research is to evaluate variation of mandibular arch forms at different heights and to determine if there is any correlation between occlusal arch and sub-gingival arch forms.

Methods: 44 subjects were selected based on the inclusion criteria and their CBCTs then were imported to Mimics software (Materialise NV, Belgium) and traced. Each tooth was sliced midsection at 4 different heights: Occlusal, CEJ, Apex and 5mm apical to the apex. At occlusal level the midpoint of the crown was calculated mesiodistally as well as buccolingually. Subsequently, midpoints between the buccal and lingual plates were located for every tooth between and including the first molars. The points were connected forming 4 splines, which then were exported to Geomorph software (cran.r-project.org, Geomorph package, Dean Adams author, Iowa State 2015) for shape statistical analysis.
Results: The variation in the arch form among subjects is significantly smaller in the Occlusal and CEJ level. The variation at apical and basal bone levels are higher than the variation at CEJ and occlusal levels. However, variation between apical and basal bone levels are minimal.

Conclusions: Mandibular dental arch form demonstrate more variation apically. It may be concluded that dental arch form variation should be considered when using standardized arch forms for different patients. The subgingival arch forms cannot be predicted from occlusal arch form. Occlusal arch shape and form may not be an indication of basal bone arch form. More information needed for detection of correlation between occlusal arch and sub-gingival arch forms.
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Introduction:

The goal of orthodontic treatment is to achieve a stable occlusion that positions all the teeth in a proper angulation and position within the alveolar bone. Correct positioning of the teeth insures a functional occlusion that places teeth in proper relationship to one another both interarch and intraarch, furthermore in accord with both hard and soft tissue post-treatment. Edward H. Angle used difference in molar relationships to classify his patients.\(^1\) He divided the occlusion into 3 types: normal relationship of the jaws, or Angle Class I; a retrognathic jaw, or Angle Class II; and a prognathic jaw, or Angle Class III. These classifications were useful for communications between professionals and for research purposes to represent dentoalveolar relationships.\(^2\) Over half a century later Larry Andrews started to add more occlusal criteria, to our understanding of what constituted a functional and esthetic bite relationship leading to the Six Keys of Normal Occlusion.\(^3\)

1. Molar interarch relationship, where the mesiobuccal cusp of the maxillary 1\(^{\text{st}}\) molar contacts the mandibular 1\(^{\text{st}}\) molar in-between the mesial and middle buccal cusp.

2. Mesiodistal crown angulation, where the gingival part of the long axis of the crown is more distal to the occlusal part of the line.

3. Labiolingual crown inclination is positive, having the occlusal portion of the crown more buccal than the gingival area.
4. The dentition is well aligned, with the absence of rotations.

5. The dentition should have tight contacts in between adjacent teeth.

6. A relatively flat occlusal plane, where the curve of Spee is not to be above 1.5mm.\textsuperscript{3,4}

Andrews studied 120 casts of patients with optimal occlusion and measured the position and angles of all teeth. The result of the measurements revealed that all casts were within a specific range and it was concluded that those outside these range have improper occlusion. These measurements were then used to create keys of occlusion; describing normal occlusion was accomplished by the use of normal ranges from looking at anatomy above the gingiva excluding all of subgingival structures.\textsuperscript{4}

As result of his studies Andrews was able to determine the average tip and torque angles for all the teeth. Furthermore, he was able to calculate norms for in/out dimensions of the labial surface of each tooth relative to a flat labial arch wire plane.\textsuperscript{3} This led him to create a prescription for all the teeth in the arch placing compensations within a bracket which would then avoid the need for placing the traditional first-, second-, and third order bends in the wire.\textsuperscript{1,2} Implementation of compensated brackets allows clinicians to position the brackets in correct position and the prescription in the brackets will theoretically lead to optimal level and aligning of all the teeth.\textsuperscript{5} As prescription brackets gained wider use and acceptance in clinical practice the focus has shifted on to ways to reduce errors in bracket positioning. The manufacturers prescribe the average height positioning for their prescription brackets during direct bonding depending on degree and level of compensation placed in their
brackets.\textsuperscript{5,6} Bracket height prescriptions are determined to put the teeth in a particular orientation relative to each other and to the underlying bone, when a full dimension arch wire is used in the arch wire slot in the bracket. The correct amount of 1st, 2nd and 3rd order movements will occur when that condition is met.

Other techniques such as indirect bonding emerged where the brackets are positioned outside the mouth on a model prior to bonding appointment to ensure proper placement of the brackets. The brackets are then transferred from the model into the patient using a guide or template tray. More recently, computer-aided custom made brackets have been developed where commercial systems such as Insignia\textsuperscript{™} (Ormco, Orange CA) or Harmony (AO, Sheboygan, WI) digitally design and mill custom made brackets that ensure that the surface of the tooth matches perfectly with the bonding surface of the bracket.\textsuperscript{7} This offers a better control in all three dimensions from the initial to finishing phases of orthodontic treatment. Combining the custom made brackets and indirect bonding technique can help orthodontists to reduce errors when bonding their patients and allow for ideal placement of the appliances to achieve more predictable results.\textsuperscript{7,8}

It is significant to note that every existing bracket system had a starting point that was based on averages developed from previous research and measurements. Today, there are variety bracket systems with different prescriptions all initiated based on those earlier studies.\textsuperscript{8} For some time researchers have believed that each patient has a special arch form and arch size and that the stability of orthodontic treatment depends
on preserving the patient’s pretreatment arch form and arch size during and at the end of treatment.\textsuperscript{9-12} Arch width and shape are important characteristics of the dental arch and generally speaking there are three main arch forms: ovoid, tapered and square that are more often used by the orthodontists.\textsuperscript{13} The arch size can be measured by evaluating arch perimeter, arch width, arch depth inter-canine and inter-molar widths.\textsuperscript{14} Clinicians need to be aware of arch perimeter since longitudinal studies have shown high probability of relapse after increasing intercanine distance, especially in the mandibular arch.\textsuperscript{15} Initially an important part of edgewise technique was bending the arch wires in order to match the patient’s dental arch. Dental casts were used in order to form custom arch wires to avoid discrepancy from the natural arch form.\textsuperscript{16} 3-dimensional digital models of the dental casts have assisted with production of prefabricated arch wires such as preformed nickel-titanium wires that have been used a great deal in the initial phases of orthodontic treatment.\textsuperscript{10,17} Some clinicians do not take into account the specific size of preformed nickel-titanium wires, since they believe the original arch shape will be restored after using stainless steel arch wires with appropriate size and shape in later stages of treatment. This method is not recommended because it causes round tripping movement of the teeth during treatment and increases the later side effects such as periodontal problems or increased incisor proclination.\textsuperscript{18}

Braun et al evaluated occlusal views of untreated human dental arches in Angle Class I malocclusion by applying a computer curve fitting program to develop a generalized
equation describing dental arch form. They concluded that the arch forms can be described by two independent measurements, intermolar width and arch depth using the mathematical Beta function formula. Their result revealed that the mean correlation coefficient of curve fit was 0.98 for the mandible and 0.97 for the maxilla.\textsuperscript{18} An earlier study by the same author revealed a variation in dental arch size related to the Angle classification of occlusion and concluded that the Beta function applies to untreated subjects with Class I malocclusion.\textsuperscript{19} This form is not generally matched by the popular preformed nickel titanium arch wire/bracket systems tested.\textsuperscript{18} In a study of subjects by Braun et al. they discovered that the intercanine and intermolar widths of upper and lower preformed arch wires were larger than the average dental arch widths in almost their entire sample. The average intermolar width exceeded the average dental arch width by 2.893 mm in the maxillary arches and 1.861 mm in the mandibular arches.\textsuperscript{18,19}

The dental arch form and size are determined by the form of the basal bones initially, and following eruption of the teeth by the circumoral musculature and intraoral functional forces.\textsuperscript{20,21} According to the “apical base” theory, the size and shape of the supporting bone are largely under genetic control, and there is a limit to expansion of a dental arch. Lundström proposed that the apical base (1) is not changed after loss of teeth, (2) is not influenced by orthodontic tooth movement or masticatory function, and (3) limits the size of dental arch.\textsuperscript{22,29} If the teeth are orthodontically moved beyond this limit, labial or buccal tipping of the teeth, periodontal problems, or
unstable treatment results could be expected. Therefore, arch form and size should be recognized as part of a morphologic human pattern.\textsuperscript{23-25}

Conventionally, basal bone has been assessed by measuring the apical third of a root or through measurement of a specific distance from the gingival margin to the mucogingival junction (MGJ) on dental casts.\textsuperscript{26-28} Previous studies evaluated the relationship between dental and basal arch forms using the WALA (Will Andrews and Larry Andrews) who proposed a band of soft tissue immediately superior to the muco-gingival junction ridge on virtual models as a reference point for measuring basal bone.\textsuperscript{28-30} By assigning points to the WALA ridge (WALA points) directly beneath the midpoints of the facial axes of corresponding teeth (FA points) they could investigate both the arch forms of the basal bone and the arch form characterized by the sites of the orthodontic brackets. Studies by Roney et al. revealed highly significant correlation between FA and WALA point widths in the canine and molar areas in class I subjects. The study also found that both arch forms derived from FA and WALA points were highly individual and could not be defined by one singular generalized shape.\textsuperscript{22,31} It should be noted that when defining the basal level the soft tissue thickness, which varies among teeth, may affect the WALA point positions which in turn may affect the basal bone arch form.

A further difficulty is that the definitions of the vertical position of the basal area of the alveolar process varies among clinicians. Some studies have explained that the apical base is in the horizontal plane that coincides with the region in which the apices
of the roots are located.\textsuperscript{33} Malocclusion of the teeth could be regarded as a problem in connection with the apical base.\textsuperscript{32} A study by Howes stated that the basal arch refers to the apical third of the alveolus and the bone that supports the alveolar processes below the mandibular teeth. He also explained that it is the most constricted area of the alveolus and is generally about 8 mm below the gingival margin.\textsuperscript{33,34}

Cone-beam computed tomography (CBCT) has started to replace traditional 2-dimensional (2D) radiographs in current practice. CBCT was developed as a way to produce 3-dimensional images of patients faster, and with less radiation than conventional medical CT. \textsuperscript{35}

Multiple two-dimensional images are gathered by having the radiation source and imaging sensor rotate around the patient’s head. Several hundred flat plane image slices are combined mathematically using a filtered back technique to create a three dimensional reconstruction.\textsuperscript{36,37} Resolution of the image depends on the voxel size; similar to a two-dimensional pixel in a plane image, the more voxels in a captured 3-dimensional image the greater the resolution of the image.\textsuperscript{38,39}

CBCT has many uses in orthodontics and dentistry for treatment planning. Panoramic radiographs and cephalograms (both sagittal and coronal views) can be reconstructed from a single CBCT for more traditional views and analysis.\textsuperscript{1} However, 3-
dimensional reconstructions have been shown to be more effective in visualizing anatomy than 2-dimensional radiographs.\textsuperscript{40} The utility of CBCT has been of special importance when planning multidisciplinary cases, evaluating supporting sub-gingival structures.\textsuperscript{41} The information gathered in a CBCT scan can be used by other specialists to increase the inherent value in proper diagnosis and treatment planning.\textsuperscript{41-42}

Although the panoramic radiograph allows for visualization of the subgingival area, because it is a 2-dimensional image it only allows the clinical to see these areas in one plane; conversely, the CBCT allows clinicians to investigate the roots in all three planes of space. It allows researchers to evaluate the bone structure that supports teeth at different vertical levels.

Numerous studies have documented the accuracy and reliability of CBCT-derived images. Tai et al. evaluated dental and skeletal dimensions using CBCT before and after application of a Schwartz appliance.\textsuperscript{43} Bayome et al evaluated the relationship between dental and basal arches with 3-dimensional (3D) virtual models and CBCT images in normal occlusion subjects and Class III subjects and concluded that dental arch form has a strong positive correlation with the basal arch form in the Class I occlusion and moderate correlation for Class III malocclusion group. Using CBCT imaging they were able show the importance of basal bone arch form in determining the dental arch form.\textsuperscript{44}
Several studies have evaluated arch dimensions in different malocclusion samples. However, the focus has mainly been on the occlusal level, the WALA point and mainly by evaluating dental casts whether plaster models or digital. The Goal of this study is to evaluate variation of mandibular arch forms at different vertical levels and to determine possibility of developing a standardized clinical arch form.
Hypotheses:

- Hypothesis: For the Caucasian patients with Class I malocclusion, we hypothesize that the arch forms will not be statistically different at 3 different sub gingival vertical levels, and compared with the archform at the occlusal level, and the archforms are generally correlated.
**Materials and Methods:**

An existing database consisting of 1735 CBCTs was screened for the sample. The database contained only de-identified DICOM files of the scans. For the screening process to take place, the individual DICOM files were imported into Dolphin Imaging software (Dolphin Imaging and Management Solutions, Chatsworth, CA) on a Boston University Orthodontic Department computer designated to research. Each DICOM file was assigned a different tab under single patient file. The tabs were labeled with the DICOM file’s de-identified name.

The 3D function within Dolphin was used to view the file, and the patient was screened for the following inclusion criteria:

- Complete permanent dentition. Any missing or unerupted teeth would exclude the patient.
- Molar relationship between a half-step Class III to a half-step Class II molar relationship.
- Canine relationship near a Class I, with a half-step range (similar to the molars) in either direction.
- No severe incisal attrition or crown irregularity
- Crowding involving 3 or fewer teeth and not exceeding 4 mm. If spacing existed, there could be no more than 6mm.
- Overjet and overbite each not being less than 0 mm or greater than 5 mm. Special note was taken if the patient had a bonded retainer or other indications of orthodontic treatment, which would differentiate the patient from an
untreated one. All patients with a Class I malocclusion and satisfying the other inclusion criteria were included in the sample.

The screening process resulted in an initial sample consisting of 44 patients that had an Angle Class I malocclusion with or without orthodontic treatment.

The list was transferred into a new spreadsheet file before being brought back to the research computer. The appropriate DICOM files were imported into the corresponding patient file and 44 files were created for the subjects. The treated and untreated subjects were compared and no significant difference were found between the two groups therefore they were combined to make them into one group.

Subject’s DICOM file was then imported into Mimics software and a new project was created for each of them. Once imported into Mimics the CBCT image was traced in the following manner:

First, a specific study was created that included all the points that needed to be traced for each subject. To create the new study “overview” was selected on the upper right corner (Fig1). Second, a new analysis template was selected under analysis overview (Fig2). Third, the new analysis was created under the change analysis (Fig3). Finally, the landmarks were then created under new the point icon and given their specific names and color (Fig4).

After creating the desired analysis a new project was initiated for each subject and the points were traced under that analysis. After creating each new project 'Measure and Analyze' was selected under the Simulate function (Fig5). The study that was initially
created for this research was then selected under analysis tab (Fig6). Each point was selected on the upper right corner and placed in the designated position on coronal, sagittal and axial slices (Fig 7).

Each tooth was sliced midsection in the 4 following levels:

1. Most occlusal part of the crown mid mesial/distal, mid buccal/lingual

2. Most coronal section were both buccal and lingual plates become visible (CEJ)

3. Apical level

4. Basal bone level, 5 mm apical to the root apex

By slicing each tooth in 4 vertical sections 4 arch forms are created at different vertical heights:

1. Occlusal

2. CEJ

3. Apex

4. Basal Bone

Each arch form includes 12 points for each tooth starting from lower right first molar to lower left first molar (Fig 8) and that resulted in 48 landmarks for each subject. For the occlusal arch form each point was selected at the most occlusal portion of the crown and then measured the midpoint of the crown both mesiodistaly and buccal/lingually. To select the points for the rest of the 3 sub gingival vertical arch forms a line was drawn from the most buccal point of the bone to the most lingual point of the bone. The
midpoint of each of these lines was measured at each height for all the teeth lower first right molar to left first molar (Fig 9).

In order to insure that the midpoint was accurately located a reference plane was created at the coronal section by picking three points on mesiobuccal cusps of the lower molars and incisal edge of lower left incisor tooth. A midpoint for each of these lines was measured and then connected these three points created a reference plane. At each vertical level then a plane was created that was parallel to the reference plane and went through the lower right incisors designated point at that sub gingival level (Fig 10-13). When selecting the points at each arch form it was assured that the point would be placed on the 1mm thick designated plane for that arch form. The alignment was verified by checking the whole skull panel, and also by scrolling inferiorly-superiorly through the axial slice. After confirmation of alignment, landmarks were placed and the tooth was traced before repeating the process on the next tooth.

After all the points were accurately selected for each arch form the 12 points at each arch level were connected using the spline feature of the program to develop four dental arch forms at the occlusal and different bone levels (Fig 14). Each spline represented an arch form, the order of the splines were as follows:

- Spline 1 = Occlusal
- Spline 2 = CEJ
- Spline 3 = Apex
- Spline 4 = Basal Bone
The four splines then were displayed within the subject’s 3-D model of the entire head in 3 planes (sagittal, coronal and axial). (Fig15-17). Any corrections could be done at that time, before exporting the points and the splines out of the software.

The four splines of each subject were then exported in TPS file format from Mimics software. The tps data for each file imported into Geomorph software for shape analysis and variation detection. The raw data were then taken through the morphometric-specific step of alignment using a generalized Procrustes superimposition, which is imperative for raw coordinate data. The function performs an analysis of shape on size, and generates generalized Procrustes Analysis plot (GPA) that describes the multivariate relationship between size and shape derived from landmark data (Fig 17). All analysis and plotting functions in Geomorph require a full complement of landmark coordinates. Either the missing values are estimated, or subsequent analyses are performed on a subset dataset excluding specimens with missing values. Generalized Procrustes Analysis is the primary means by which shape variables are obtained from landmark data.

Geomorph was also used to preform a principle component analysis on each data set where it plotted each set of data with respects to their principal components, each number on the plot represents a subject’s arch form at the specific level (Fig18).

Geomorph was then used to perform a two-block partial least squares analysis, and generated a plot that described the multivariate relationship between size and shape. The data are displayed in 3D plots to evaluate the distribution of the points in 3 dimensions (Fig19).
The variation was explained by each principle component (PC), in terms of raw variation, proportional variation, and cumulative proportional variation. A principal components analysis helped visualize shape variation and plotted two dimensions of tangent space for the set of Procrustes-aligned specimens.

The pairwise differences between all vertical arch forms were computed and significant testing of multivariate variances (MVV) were conducted in a non-standard form. All MVVs were calculated using the sum of the trace of the VCV matrix. Significance between pair differences was assessed using permutation through "label switching". That is, individual specimens were permuted among groups, then new MVVs computed. These are the permuted MVV differences. P-values were obtained by counting the number of times a difference equal to or more extreme than the observed difference occurred during permutation, then divided by the number of permutations.

5000 permutations test was executed which is random re-samplings of the data and histograms were plotted comparing every 2 arch forms. The histogram is a visual representation of the results of the variance between two locations. The following arches were compared: occlusal vs CEJ, occlusal vs apex, Occlusal vs Basal bone, CEJ vs apex, CEJ vs Basal bone, Apex vs Basal bone (Appendix A: Fig 24-30). This was a 1 tail test and the red line indicated the p value of the result. If the red line was close to zero then the result was not statistically significant.
Fig1: Select overview to create new analysis

Fig2: Select “New” under analysis template
Fig3: Create new analysis under “Change analysis”

Fig4: Create new landmarks
Fig 5: “The Measure and Analyze” was selected

Fig 6: Select the initially created study
Fig 7: The landmarks selected on a Coronal, Sagittal, and Axial slices

Fig 8: The 12 points depicted on the arch
Fig 9: Measuring the midpoint of the basal bone

Fig 10: Planes selected at each level
Fig 11: The 4 planes in coronal view

Fig 12: Sagittal view of the plane with respect to 3D model of the subject
Fig 13: Coronal view of the 4 planes with respect to the 3D mode

Fig 14: The 12 points connected on the occlusal arch form
Fig 15: 4 splines depicted on the 3 D model of the subject, coronal view

Fig 16: 4 splines depicted on the 3 D model of the subject, sagittal view
Fig 17: 4 splines depicted on the 3D model of the subject, axial view.
Fig 18: GPA Plot of the Apical Arch Points

Fig 19: PCA Plot of Apical Arch Points
RESULTS:
Among the group of untreated Caucasian patients with a Class I relationship there are 36 PCs that explain the variations in each arch forms for the 44 subjects. Tables 1-4 show the amount of variations introduced by each principle component. Using PC1 & PC2 the principle component analysis plot was made for the 4 vertical levels of the subjects (Fig20-23).

Figure 20: PCA plot of Occlusal level
Figure 21: PCA plot of CEJ level

Figure 22: PCA plot of Apex Level
Figure 23: PCA plot Basal bone Level

Caucasian Untreated Patients Compared to Treated Caucasian Patients

When comparing variation among the group of untreated Caucasian patients with a Class I relationship, the variation in arch forms increases apically (Table 1). Geomorph software completed GPA analyses on all raw data, than summed the trace of the covariance matrix of the procrustes aligned coordinates, to get the measure of variability.
Table 1: Variance values of 4 arch form

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<td>Occlusal Level</td>
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<tr>
<td>CEJ Level</td>
<td>0.0039</td>
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<tr>
<td>Apex Level</td>
<td>0.0091</td>
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<tr>
<td>Basal Bone Level</td>
<td>0.0087</td>
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The arch forms at apical levels and basal bone level are significantly different from both occlusal and CEJ levels.

Table 2: Difference between variances

<table>
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<th>CEJ</th>
<th>Apex</th>
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<td>CEJ</td>
<td>-0.0007</td>
<td>-</td>
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</tr>
<tr>
<td>Apex</td>
<td>-0.0053*</td>
<td>-0.0046*</td>
<td>-</td>
</tr>
<tr>
<td>Basal Bone</td>
<td>-0.0059*</td>
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<td>-0.0006</td>
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</table>

Correlations between the occlusal arch form and 3 sub-gingival arch forms were examined as a 2-block partial least squares correlation. When comparing the occlusal arch form with 3 sub-gingival arch forms among the group of Caucasians with a Class I relationship more data is needed to determine conclusive results.
Table 3: Correlation between occlusal level & 3 sub-gingival level

<table>
<thead>
<tr>
<th>Correlation</th>
<th>Correlation</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occlusal/CEJ</td>
<td>0.893</td>
<td>0.001&gt;</td>
</tr>
<tr>
<td>Occlusal/Basalbone</td>
<td>0.890</td>
<td>0.001&gt;</td>
</tr>
<tr>
<td>Occlusal/Apex</td>
<td>0.890</td>
<td>0.001&gt;</td>
</tr>
</tbody>
</table>

Both apex and basal bone levels were significantly more variable than the occlusal level. The CEJ level is also significantly more variable than both basal bone and apical levels.

The GPA of each arch form was then plotted in order to represent the 3D distribution of every 12 points for all 44 subjects at all 4 vertical level (Appendix B: Fig 31-34)

**Intra-examiner Reliability:**

The same examiner retraced the landmarks for 4 random subjects (10% of subjects), with 1 month in between the tracings and the coefficient of reliability was determined. A Pearson Correlation analysis was performed to show the reliability between the two readings for all landmarks and intra-examiner error was found to be 87%, demonstrating a strong correlation.
DISCUSSION:

Objective 1:

Understanding the relationship between the dental and basal arch forms is of diagnostic importance. This study focused on the mandibular arch form since it is less open to orthodontic intervention and is used as the basis treatment planning for both maxillary and mandibular clinical arch form. Also, when evaluating the basal bone for maxilla at 5mm apical to root apices of the teeth it would invade maxillary sinuses or nasal cavity preventing assessment of the basal bone in the maxilla.

Previous studies mostly have focused on the intercanine and intermolar widths to compare occlusal arch form and dental arch forms.\textsuperscript{10,11} Dental arch forms have been classified by picking anatomical points on the teeth such as the incisal edges or molar cusp tips. Using these anatomic points researchers developed multiple descriptions and mathematical models for the optimal arch form including the catenary curve, elliptic curve, conic section, spline curve, beta function, paraboloid, and others.\textsuperscript{18,19} These studies applied polynomial curves or vector quantization algorithms to series of FA points to determine the optimal archwire blank form.\textsuperscript{45} Despite the many efforts to analyze arch forms, clinicians lack the knowledge of whether or not one general formula or equation can be applied to characterize dental arch form.\textsuperscript{46}
Using CBCT imaging in this study enabled the evaluation of the subject’s arch forms and shape analysis in a direct and comprehensive manner by measuring basal bone directly and tracing landmarks for each tooth both in posterior and anterior region.

When comparing the four mandibular arches at four vertical heights in the untreated Caucasian group, variation increased moving apically (table 1, ADD A PAGE NUMBER where table 1 can be found). The shape of the arch is initially determined by the basal bone and the shape of the basal bone is more variable compared to clinically visible dental arch form. This arch form variation between sub-gingival structures and occlusal structures need to be evaluated during orthodontic treatment in order to improve arch co-ordination.

When comparing the four arch forms at different vertical heights the arch form at apical and basal bone levels demonstrate significantly more variance comparing to both CEJ and occlusal levels. The basal arch form has almost no correlation with the occlusal arch form, indicating there is another factor that is determinant in forming the final human dental arch form which is clinically visible. This determining factor may be the tongue, the shape of the mandibular bone itself, the buccal musculature, a combination of all of these or a different combination of genetics and environment.

Previous studies used WALA points to determine basal bone level and chose the points either on plaster or digitized models they did not address variation in the arch forms. More recent studies used CBCT imaging to evaluate basal bone by selecting digitized root center points (RC) for all the teeth. The RC points were traced on CBCT and were digitized at the center of the root on transverse section parallel to the occlusal plane at
the level of coronal third of canine roots.\textsuperscript{47-48} The authors explained that points were selected at that level to be in the same correspondence of the WALA point. Even though Suk et al. used 3D imaging to trace the landmarks the basal bone arch still referred to same arch form as previous arch form depicted by WALA points.\textsuperscript{44}

The method in this study offers a more accurate technique evaluating sub-gingival supporting structures.

Objective 2:

When evaluating the correlation between the occlusal arch form to the other 3 sub-gingival arch forms at 3 different vertical heights in a group of non-treated Caucasians with class I occlusion, all 3 sub-gingival arch forms results are not correlated. More data is needed to confirm the result from previous studies that looked at correlation between basal bone level and dental arch level.

The dental arch has been represented by different anatomical points (ie, incisal edges and cusp tips vs FA points) in different studies and this lack of consistency has caused much of the discrepancy in representation of dental arch form.\textsuperscript{22} There appears to be little agreement as to specifically what determines the human dental arch is or at least what points should be used to represent it. Many past studies have defined the normal dental arch as an abstract curve lying on the occlusal plane, the size and shape of which is determined by the position of the buccal cusps of the molars and bicuspid, the
canine tips and the edges of the incisors. However, the points traced in this study are more comparable to definition of Macnail and Scher’s dental arch. In their study the dental arch form was determined by the central fossae of the molar teeth, the occlusal fissures of the premolars, and the incisal fossae of the canines and incisors. The measured midpoint of the occlusal surface of the teeth (both buccal lingually and mesio-distally) are also on the central fossa on posterior teeth and close to the cusp on canine and incisal edge on anterior teeth.

Bayome et al. evaluated the relationship between mandibular dental arch basal arch by tracing the facial axis (FA) points with root centers (RC) on CBCT images of subjects. In addition FA and WALA points were digitized on 3D models and they found a strong correlation between dental and basal intercanine and intermolar width and depth. The RC point corresponds to the WALA point, but is located inside the basal anatomical structure, and it approximates the center of resistance of each tooth. The basal arch may be more accurately expressed using the landmark directly on basal bone rather than the WALA points on a virtual model. The study concluded that the dental and basal anterior and posterior arch widths were strongly correlated in normal occlusion and moderate correlations in the Class III group. Based on their finding the dental arch form corresponds to the basal arch form more strongly in normal occlusion than in Class III malocclusions, supporting the “apical base” theory that the dental arch form is initially shaped by the configuration of its supporting bone, which limits dental arch expansion. Recognition of the dimensions and shapes of the dental and basal arch forms, as well as their relationship, may help clinicians to accurately position teeth
during treatment and preserve patients’ arch forms, which could in turn lead to more stable and predictable treatment outcomes.

It will be useful to determine the presence of correlation between occlusal arch and sub-gingival arches for clinicians to better understand the relationship between dental and basal arch forms in Class I occlusion. The stability of the treatment outcome may be questionable without consideration for the relationship between the dental and basal arch.

Strength:

Using CBCT imaging all the points were traced by measuring the basal bone directly and provided more accurate measurements rather than previous 2d images or using 3d and plaster models. This study provides more comprehensive overall shape analysis of dental arch forms at 4 different vertical heights.

FUTURE STUDIES:

All the subjects in this study has Class I dental malocclusion. Comparing Class II and Class III malocclusions archforms to these subjects can determine if the same results apply in different maloocclusions. Subjects with different skeletal patterns could also be evaluated. Furthermore, arch forms of subjects with different age groups and ethnicity can be assessed.
Summary:

1. We traced the CBCTs of 44 subjects, divided the mandible into 4 different vertical heights to evaluate the arch form and shape.

2. When comparing the 4 arches the variation in the arch form increased when moving apical.

3. The Apical and Basal bone arch forms are significantly more variable than both CEJ and Occlusal arch forms

4. More data is needed for more conclusive results regarding correlation between occlusal arch and sub-gingival arches

Conclusion

The mandibular arch form at occlusal and apical/subapical levels express similar arch form & shape pattern among a cross-section of patients with Class I malocclusion. The clinically observable arches among patients with similar occlusion are comparable. The subgingival arch forms cannot be predicted from occlusal arch form (except for the CEJ arch form). Finally, occlusal arch shape and form may not be an indication of basal bone arch form.
Work Cited:


26. J.C. Brash. The etiology of irregularity and malocclusion of the teeth. (2nd ed.) Dental Board of the United Kingdom, London (1956)


32. Lundström, A.F. Malocclusion of the teeth regarded as a problem in connection with the apical base. AJO-DO. 1925; 11(11) :1022-42.


Appendix A: Histogram of 1 Tail, 5000 Permutations

Figure 24: Histogram of Occlusal over CEJ

Figure 25: Histogram of Occlusal over Apex
Fig 26: Histogram of Occlusal over Basal Bone

Fig 27: Histogram of CEJ over Apex
Figure 28: Histogram Apex over Basal Bone

Figure 29: Histogram of CEJ over Basal Bone
Appendix B: GPA Plots For Each Arch Form

Figure 30: Occlusal Arch form

Figure 31: Apical Arch Form
Figure 32: CEJ Arch Form

Figure 33: Basal Arch Form
BEROKH BAVAR
1079 Commonwealths Ave, Apt 205
(857) 221-2337 – Bbavar@bu.edu

ACADEMIC EXPERIENCE

CAGS/MSD in Orthodontics & Dentofacial Orthopedics
July'13-May’16
- Member of American Association of Orthodontists
- Member of International Association of Dental Research
- Member of National Board of Dental Sciences
- Member of Massachusetts Dental Society

Doctor of Dental Medicine, Boston University Dental School
Aug ’09-May’13
- Graduated Magna Cum Laude
- Member of ASDA Social Committee
- Member of American Association of Women Dentists
- Member of Big Brother/Big Sister Program
- Member of Boston University Dental School Research Journal Club
- Volunteer at Community Outreach Programs

Bachelor of Life Science (BSc.), McMaster University
Sep’03 - Apr ’08
- Graduated with Distinction
- Dean's Honor List 2007, 2008
- McMaster Honor Award, 2003

RELEVENT EMPLOYMENT EXPERIENCE

Orthodontist, Franciscan Hospital for Children
May’15- May’16 (In fulfillment of residency requirements)
- Performed Orthodontic diagnosis and treatment planning in a specialty Pediatric hospital
- Performed routine as well as interceptive Orthodontic treatment

Associate Dentist, Boston Care for Homeless Program, Dr. Alan Filzer
May’12-July’12
- General dentistry as part of Boston University externship program
- Operative procedures

Dental Assistant, Dr. Alireza Karbassi DMD, MSD, Karbassi Orthodontics
Feb'09-Jul'09, May’10-Aug’10
• Adjusting, removing, replacing wires and ligatures
• Preparing material for cementation and impressions
• Assisting in creating retainers, taking the impressions and delivering oral health instructions and care for orthodontic devices

**Dental Assistant, Dr. Ata Nasirzadeh DDS, Elles Birch Dental Office**  
May’08-Oct’08

- Aided the doctor with setting up instrument trays, taking medical history, taking radiographs, and assisting the doctor during various procedures
- Sterilizing and disinfecting instruments, and helping with office upkeep

**Receptionist, North York Medical Imaging Center**  
Oct ’06–May’07

- Scheduling appointments, greeting patients, and preparing them for medical exams
- Assisting patient and the consultant throughout procedures

**Certifications**

- *Incognito (3M Unitek)*: May 2015
- *ABO Written Examination*: April 2015
- *WREB*: March 2013
- *NBDE Part II, General Dentistry (USA)*: Jan 2013
- *NBDE Part I, General Dentistry (USA)*: Feb 2010
- *CPR*, Boston, MA: August 2015

**Professional Development Courses**

- *Yankee Dental Congress*, Boston, MA: attending annually since 2009
- *Tweed Course*, Tucson AZ: September 2014
- *FACE Treatment Course*, Boston, MA: Sep 2015

**Research Experience**

- *Mandible Dental Arch Form Determination From CBCT at 3 Levels,*
• **Orthodontic treatment need is associated with Oral Health-related Quality of Life in Teens**, 
Mentor: Dr. Judith Jones DDS, MPH, Dr. Leslie Will DMD, MSD, Chair of Orthodontics in Dentistry 
Dec’11-May’13

• **Oral Health-related Quality of Life pre and post dental treatment**
Mentor: Dr. Judith Jones DDS, MPH, Chair of General Dentistry 
May’10-Aug’10

*References available upon request*