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ABSTRACT

Title of Thesis: Alveolar Bone Height Changes in Patients Treated with Conventional and Damon Brackets

Akinwale Akinwande: Master of Science, 2019

Thesis directed by: Monica Schneider DDS, MS
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Objective: To compare the distance between the cementoenamel junction (CEJ) and marginal alveolar bone (MAB) on the buccal root surfaces of the maxilla and mandible after orthodontic treatment using Conventional bracket system (CS) and Damon bracket system (DS).

Methods: The sample included 30 patients, 14- 46 years of age (13 treated with CB and 17 with DB) with moderate to severe crowding treated nonextraction. We compared pre and post-alignment cone beam computed tomography (CBCT) images to measure the bone height (BH) changes of 24 buccal surfaces for each subject.

Results: Even though we found great variability in BH levels, there was a statistically significant difference (*Paired t-test*: p value ≤ 0.05) between pre and post- alignment CBCT images of teeth in both Conventional and Damon groups. There was no statistically significant difference (*independent t-test*: p value ≤ 0.05) in BH changes when comparing the 2 bracket systems.

Conclusion: The bone height levels changed after orthodontic treatment with both Conventional and Damon bracket systems, but there appears to be no significant difference in alveolar bone height changes between the two brackets in this study.

Alveolar Bone Height Changes in Patients Treated with Conventional and Damon Brackets

by
Akinwale Akinwande

Thesis submitted to the Faculty of the Graduate School of the
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of the requirements for the degree of
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Thanks to the private orthodontic practices for giving me permission to use the CBCT images of patients from their offices.

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Teeth and supporting structures:

In a normal occlusion the teeth are held in the upper (maxilla) and lower (mandible) jaws, they are invested within a delicate network of supporting structures known as the periodontium. The periodontium serves as the source of attachment of teeth to surrounding tissues, which in the healthy state enables the teeth to perform their optimal function to breakdown food in preparation for swallowing and digestion. Periodontium consists of both soft and hard tissue namely cementum (lines the attachment surface of the root), periodontal ligaments, alveolar bone and gingiva (gums). The alveolar process is the thickened ridge of bone that contains the tooth sockets on the jawbones that hold the teeth. The alveolar crest is the most cervical rim of the alveolar bone proper. In healthy situation, the alveolar crest is slightly apical to the CEJ by approximately 1.5- 2 mm (Nanci, 2013). The alveolar crests of neighboring teeth are also uniform in height along the jaw in healthy situation (Bath-Balogh, 2011). Dehiscence is a loss of alveolar bone (>2 mm) on the facial (rarely on the lingual) aspect of the tooth that leaves a characteristic oval-shaped defect and root exposed from the CEJ apically. The defect is of variable length along the root surface, one to two millimeters long or extends the full length of the root. The three characteristic features of dehiscence include, alveolar bone loss, gingival recession and root exposure. A fenestration is a “window” of bone loss on the facial or lingual aspect of a tooth that places the exposed root surface directly in contact with gingiva or alveolar mucosa. It can be distinguished from dehiscence in that the fenestration is bordered by alveolar bone along its coronal aspect (Langlais, 2016)

Gingival recession in its localized or generalized form is an undesirable condition resulting in root exposure. It is often not esthetic and may lead to sensitivity and root caries. Exposed root surfaces are prone to abrasion (Kassab et al, 2003). Multiple etiologic factors have been identified as the risk factors and cause of this condition; these include aging, anatomical, physiological, pathological, trauma, hygiene and aberrant frenal attachment. Anatomical factors that have been related to recession include fenestration, dehiscence of alveolar bone, abnormal tooth position in the arch (crowding), aberrant path of eruption of the tooth and individual tooth shape. All these factors are interrelated and may result in an alveolar osseous plate that is thinner than normal that may be susceptible to resorption. The buccal placement of the root relative to adjacent teeth causes the cervical portion to protrude through the crestal bone that may lead to very thin marginal bone and the occurrence of dehiscence.

Etiology of tooth size/ arch length deficiency (crowding)

Malocclusion is the abnormal alignment of the upper and lower teeth. Tooth size-arch length discrepancy is a condition that affects the arrangement of the permanent teeth in the dental arch leading to crowding or spacing. Teeth crowding is considered a common oral health issue observed among various races, and in both genders. Discrepancy between tooth size and arch length is known as the primary cause of malocclusion (Nakhjavani, 2014). This problem directly affects occlusion and esthetics; it also causes inability to maintain good oral hygiene. Periodontal disease secondary to crowding may manifest in older ages.

About 65% of the entire US population has malocclusion, out of which only 5% have malocclusion of a known cause and 60% have malocclusion of unknown cause. The known causes of malocclusion include diseases, syndromes, trauma and infections. It has been suggested that the unknown causes of malocclusion is the result of a poorly understood interplay between a combination of genetic and environmental factors.

The genetic factors describe the pattern of inheritance regarding genotypes of teeth and jaw size (Normando et al, 2013); the role the environment plays is multifactorial. Dental caries and malocclusion while now highly prevalent public health diseases are both surprisingly rare within the pre-industrial skeletal and pre-historic fossil records, and also seldom seen in many present-day non-westernized cultures. According to Proffit, 2007, the fact that malocclusion now occurs in a majority of the population does not mean that it is normal; skeletal remains indicate that the present prevalence is several times greater than it was only a few hundred years ago. Crowding and misalignment of teeth was unusual until relatively recently, but not unknown (Boyd, 2011).

In a recent publication titled The Evolution of the Human Head, Daniel E. Lieberman, 2011, noted that the jaws and faces of modern man do not grow to the same size that they used to. Pre-historic skulls have broad faces and broad dental arches while modern day skulls exhibit narrower faces and narrower dental arches. Biological anthropologist Clark Spencer Larsen, 2013 in his lecture on how diet can affect the growth of the skull, talked about how agriculture instigated a fundamental change in human craniofacial growth and development. The introduction of cooking vessels was an impactful innovation that allowed humans to make soft mushy food that required little chewing. This culinary adaptation led to major changes in craniofacial growth and development, resulting in some adverse outcomes that include reduced robustness, increased malocclusion and increased tooth crowding. Pre-industrial groups ate very tough, fibrous, low calorie plant foods as well as uncooked meat, which meant that they had to chomp through skin, cartilage and sinew. Farmers on the other hand can make porridges and stews that provide more calories for less chewing effort. Evidence for the significance of having to chew much more and harder to get the same amount of calories is that the skulls found with good occlusion and straight teeth also show signs of extensive wear on the teeth. Ancient populations ate a diet that wore down their teeth more than farmers. They had stronger Masseter and Temporalis muscles, which are involved in chewing. They spent most of the day chewing on hard things, which could wear down their teeth and exert enough direct and indirect force on the skull to morph the facial skeleton and dental arch. Thorough analysis of dental data from the Amarna project (Rose, 2009) has shown that Egyptian and most ancient teeth have excessive tooth wear with dentine exposure on the occlusal surfaces of even the youngest individuals. Malocclusion is rare in Amarna but it is common in America. Tooth wear is extensive in Amarna yet rare in America.

Weston A. Price, 1939 in his book Nutrition and Physical degeneration published a report of his study of the oral health condition of civilized groups living on modern diet, found that they had unhealthy and crooked teeth, while isolated groups living on native diets had excellent teeth. Even though the teeth exhibited signs of wear, they were straight. The author observed a significant morphological difference in the face, dental arches and occlusion between the isolated groups who maintained native diets and the children who were born to parents who adopted modern foods of commerce.

Raymond Begg, 1954 later supported this finding, when he noted that primitive man ate a coarse diet that led to interproximal wear of teeth, reducing the mesiodistal width of permanent dentition. This did not result in spacing between teeth because of mesial migration of the posterior dentition, maintaining tight contact points between abutting teeth. Begg found that in Australian aboriginal populations there was a loss of 10 mm or more of interproximal tooth structure, which allowed for maintenance of anatomically correct occlusion without crowding. Studies have attributed modern dental crowding to the current availability of a more processed, softer, diet resulting in less interproximal wear. Additionally, studies have shown that there is a strong genetic contribution to dental crowding.

Orthodontic correction of tooth size/ arch length deficiency (crowding)

Crowding is a common problem faced by clinical orthodontists, this is often resolved by the expansion of the original arch form in the antero-posterior or transverse dimensions, the reduction of tooth mass through extractions or interproximal reduction, or a combination of the two.

Expansion to resolve crowding:

Arch form expansion in the antero-posterior (A-P) dimension often lead to proclination of the upper and lower incisors and a more protrusive lip posture, which is frequently an undesirable side effect. Skeletal expansion in the lateral dimension is possible, before the fusion of the mid-palatal suture (suture closes at ages 15 in females and 16 in males). Expansion is usually unsuccessful after closure of this suture because there is little or no basal skeletal movement and changes in width are due to tipping of the teeth within the confines of the alveolus (Vanarsdall, 1999).

Deviation from a patient's natural arch form, through expansion in either A-P or transverse dimensions, has been criticized in the literature as having poor stability because of the counter-expansive force of patient's facial musculature. In the lower arch, which is often thought of as the limiting arch in orthodontic treatment, the lower incisor cannot be proclined beyond 2mm without sacrificing treatment stability because lip pressure significantly increases as this point (Proffit, 2013). Expansion of the pre-treatment mandibular intercanine width has been found to be unstable (Proffit, 2013). Conversely, posterior arch expansion distal to the canines may have more stability, because the force exerted by the lips are relatively low in the posterior arch and expansion across the premolars and molars is more likely to be maintained (Proffit, 2013). Tipping the teeth too far laterally or labially would lead to periodontally compromised teeth by causing dehiscence, fenestration or both through the bone. Fenestration becomes more likely as the incisors are advanced and with transverse movement beyond 3 mm (Proffit, 2013).

Extraction to resolve crowding:

To determine if extraction is required as part of a treatment plan to resolve tooth size arch width discrepancy, a critical factor to consider is the amount of crowding present in the arch. In Class I cases with less than 4 mm of crowding rarely require extraction, between 5 to 9 mm of crowding are borderline extraction cases with both extraction and non-extraction options as possible treatment possibilities, and more than 9 mm of crowding almost always requires extraction (Proffit, 2013).

There have been numerous philosophical swings on the best approach to resolve crowding throughout the orthodontic community. As early as the early 1900 when the orthodontic specialty was started, controversy surrounds the decision to extract or not to extract teeth as part of a treatment plan to resolve crowding and still continues till this day. Edward Angle, “the father of modern orthodontics,” suggested that a full complement of teeth was essential to a proper occlusion. He set a classification scheme of occlusal relationships, which, was based on a defined dental relationship, and little importance was given to facial proportions and esthetics (Profitt, 2013). Angle felt that new bone could be induced to grow to support a full complement of teeth through mechanical means (Angle, 1902 in Bernstein, 1992, p. 466), similar to the beliefs of the Damon philosophy today.

There was a debate in 1911 between Calvin Case and Edward angle at the National Dental Association. Angle's followers prevailed, and by the 1920s most practitioners did not perform extractions for orthodontic purposes (Dewel, 1942). It is important to note that in many of the orthodontic treatments carried out with "non-extraction" at this time, practitioners observed that these cases finished with bi-dental (bi-maxillary) protrusion, poor facial esthetics, questionable stability of the teeth and health of the periodontium. In the 1940s and 1950s, prominent practitioners (Charles Tweed and Raymond Begg) unhappy with these results noted that crowding was often resolved through proclination of the mandibular incisors with post-retention relapse occurring as the lower incisors returned to the pre-treatment position over the basal bone (Tweed, 1944). Tweed developed a philosophy based on centering the mandibular incisor over the basal bone of the mandible, dismissing the previous belief that the bone would follow teeth into a protruded position. Often, obtaining this goal, led to the extraction of premolars as part of the treatment plan. However, over time, many practitioners expressed concerns about the "dished- in" profile and facial appearance associated with four-premolar extraction. Speculation that extraction may harm facial esthetics is based on the reduction of dental volume available for lip support. Dissatisfied practitioners who strongly value facial esthetics disagreed with this philosophy and the pendulum swung back towards non-extraction.

Today, increasing importance has been placed on frontal facial esthetics, with the position of the upper incisor within the smile arc of utmost importance (Shook, 2016). Patients often resist extractions due to the sacrifice of usually healthy teeth and the history of compromised facial esthetics due to previous overuse of treatment with extractions. Most contemporary orthodontists feel that extractions are necessary in certain cases, but should be avoided if when doing so would compromise facial esthetics (Shook, 2016).

Damon philosophy (non-extraction to resolve crowding):

In 1996, Dwight Damon introduced the Damon SL I passive self-ligation appliance. The initial design has undergone several modifications, currently making the Damon appliance what is perhaps one of the most widely known self-ligation brackets available (Zreaquat, 2011).

The Damon philosophy challenges the long held standards of diagnosis and treatment of orthodontic patients. Patients who would require extraction can be successfully treated by non-extraction through the use of the Damon appliance system. The use of low force, low friction appliance systems has claimed to aid in the development of optimal arch forms and tooth positions without the extraction of teeth. Central to the Damon System philosophy is the idea that through the use of passive self-ligation brackets, very light forces, and high-tech archwires, the force of a patient's lips, tongue, and facial muscles can be readapted to create a new force equilibrium and arch form (Damon, 2005).

Passive self-ligation brackets do not interact with the archwire and function as a tube through which the wire travels. Many practitioners find the idea of self-ligation attractive because the Damon philosophy claims that this new arch form can manage crowding in many cases without necessitating extractions (Chen, 2010).

Although it has been affirmed that improved alveolar bone formation occurs, the effects of archwire expansion on the alveolar bone surrounding the teeth remain largely unknown. Studies have shown that alveolar dehiscence and fenestration are common in different types of malocclusion possibly leading to gingival recession and additional bone loss during orthodontic treatment.

Dr. Damon presents several case reports in which posterior transverse expansion of the dental arch occurs without an increase in the mandibular intercanine width, proclination of the anterior teeth, or distalization of the molars (Damon, 2005). Damon coined the term the “Fränkel effect” to explain this posterior width increase after the appliance developed by Rolf Fränkel, which similarly aimed to modify the “natural interplay of forces” and reshape the dental arch (Fränkel, 1969). By removing the pressure from the orofacial musculature, through the use of buccal shields on the appliance, Fränkel measured expansion of 5 mm in the premolar region (Fränkel, 1969). Fränkel postulated that the buccal shields stretched the soft tissues leading to apposition of new bone in the apical base area (Fränkel, 1969). This idea is similar to the Angle’s philosophy from the early 1900s that new bone would develop to accommodate all of the teeth when aligned. Dr. Damon suggests that with his appliance teeth can be moved in all planes of space without excessive tipping and that the teeth remain fully encased in alveolar bone through boney apposition (Damon, 2005).

With the Damon System the posterior arch expansion, or Fränkel effect, is believed to occur through the use of small diameter initial wires (typically 0.014 inch Copper NiTi) with broad arch forms rather than with buccal shields. The period between wire changes is also elongated to allow for full expression of the wire. The Damon philosophy claims that a new balance of the facial and tongue muscles results because the posterior expansion of the dental arch allows the tongue to lift and move forward allowing for a new equilibrium of forces to be established (Damon, 2005).

The Damon philosophy states that anterior movement of the incisors does not occur when resolving crowding with the Damon appliance because the facial muscles, the *Orbicularis Oris*, *Mentalis*, and *Depressor Labii inferioris*, resist proclination of the anterior teeth "Lip Competency Effect". It is a combination of the Fränkel and Lip Competency effect that explains how crowding is resolved with the Damon appliance system in cases that would by previous standards require extraction.

The claim of lack of incisor proclination with the Damon system was supported by a 2010 systematic review, which showed a small, but statistically significant, difference in incisor proclination in patients treated with Damon brackets vs. conventional brackets. The review of 3 studies of a high level of evidence, showed 1.5 degrees less incisor proclination in those treated with Damon brackets than those treated with conventional brackets (Chen, 2010). However, one study included patients who had undergone extractions. Thus standardization was lacking among the articles included in the review and the author suggested more research, of high scientific caliber must be conducted on this topic.

Cone Beam Computed Tomography (CBCT):

Orthodontists have historically relied on 2-dimensional (2D) imaging for diagnosis and treatment planning as well as to monitor treatment progress and growth (Orhan, 2014). These 2D imaging modalities are well known to include errors including magnification, geometric distortion, superimposition of structures, projective displacements (which can elongate or foreshorten an object), rotational errors, and linear projective transformation (Kapila, 2011).

With the introduction in the late 1990s of computers capable of the complex computations and x-ray tubes capable of continuous exposure, 3-dimensional (3D) imaging became a possibility in the dental office through the use of cone beam CT machines which were simultaneously reduced in size and became inexpensive enough for routine dental use (Scarfe, 2008). Practitioners can now visualize and measure true 3D anatomies of patients. CBCT in orthodontics is commonly used for treatment planning, dental structural anomalies, anomalies in dental position, compromised dento-alveolar boundaries, asymmetry, anteroposterior discrepancies, vertical discrepancies, transverse discrepancies, TMJ signs or symptoms, dentofacial diformities and craniofacial anomalies, conditions that affect airway morphology, specific surgical procedures, orthodontic mini-implants used as TADS and maxillary expanders (AAOMR, 2013)

The use of CBCT over traditional, medical CT in maxillofacial imaging has led to many benefits including: rapid scan time, beam limitation, increased image accuracy, and reduced patient radiation dose. CBCT scans can be completed in a much shorter time than traditional CT, leading to fewer artifacts due to patient movement. Many CBCT units allow the practitioner to select a determined field of view (FOV) based on the structures, which must be visualized. This is desirable because the irradiated field may be limited. CBCT imaging is also highly accurate with voxel resolution ranging from 0.4 mm to .076 mm. Images thus achieve a level of resolution, which is accurate enough for direct measurement, in a 1:1 ratio in all three planes of space with the original object, and no distortion or magnification (Scarfe, 2008).

Published reports have indicated that the effective dose for CBCT ranges from 29-477 μSv, depending upon the machine and FOV. The large range of radiation exposure dosages with CBCT units is due to the fact that the x-ray beam may be continuous or pulsated, with pulsation resulting in less radiation exposure to the patient (Scarfe, 2008). Compared to traditional CT, which has an effective dose of approximately 2000 μSv, there is a large dose reduction with CBCT, between 76.2 – 98.5% (Scarfe, 2008).

The generation of x-rays used in CBCT imaging has also changed in recent years, manufacturers have moved from aluminum filtration to copper at the source (x-ray tube), which has greatly reduced the amount of scatter radiation reaching the patient and successfully cut down the effective dose and made CBCT safer (Ludlow, 2015).

When comparing CBCT to conventional 2D imaging methods, CBCT does not dramatically increase the patient radiation exposure. Dosages for panoramic radiographs range from 14.2-24.3 μSv, lateral cephalogram 10.4 μSv, and a full mouth series 13-100 μSv (Kapila, 2011). The combined radiation exposure from multiple 2D images is usually just slightly lower than that of a CBCT scan, while providing the practitioner with significantly less diagnostic information. The ability to view structures in 3D and the relatively small difference in radiation exposure to the patient has led many practitioners to implement the use of CBCT radiography for all patients rather than using a combination of multiple 2D imaging methods. CBCT was used in this study due to the ability to examine the position of the teeth and bone in both the A-P and transverse dimensions.

This retrospective study proposes to evaluate the occurrence of dehiscence and fenestration before and after orthodontic treatment in patients treated with the Conventional brackets and the Damon passive self-legating brackets using CBCT images.

Three specific goals are proposed:

Goal 1) to determine how much change occurs in BH on CBCT images at T1 and T2 with Conventional brackets

Goal 2) to determine how much change occurs in BH on CBCT images at T1 and T2 with Damon brackets

Goal 3) to determine which, (if any) of these two bracket systems cause more change (decrease) in BH.

HYPOTHESES:

Hypothesis I: Conventional brackets pre-alignment vs. Conventional brackets post-alignment measurement.

Null Hypothesis: There will be no significant change in alveolar bone height measured on CBCT images between Conventional brackets pre-alignment vs. Conventional brackets post-alignment.

Research Hypothesis: There will be a change in alveolar bone height measured on CBCT images between Conventional pre-alignment vs. Conventional brackets post-alignment.

Hypothesis II: Damon passive-self ligating brackets pre-alignment vs. Damon passive-self ligating brackets post-alignment measurements

Null Hypothesis: There will be no significant change in alveolar bone height measured on CBCT images between Damon passive-self ligating brackets pre-alignment vs. Damon passive-self ligating brackets post-alignment

Research Hypothesis: There will be a change in the alveolar bone height measured on CBCT images between Damon passive-self ligating brackets pre-alignment vs. Damon passive-self ligating brackets post-alignment

Hypothesis III: Conventional treatment changes vs. Damon treatment changes

Null Hypothesis: There will be no significant change in alveolar bone height between subjects treated with Conventional vs. Damon brackets.

Research Hypothesis: The alveolar bone height change will be greater for the Damon group vs. the Conventional group**.**

This is because the Damon philosophy claims to align teeth without extraction or IPR (interproximal stripping); thus it is speculated that the roots of the teeth are pushed out of the alveolar housing resulting in further decrease in the alveolar bone height (dehiscence) compared with the conventional.

MATERIALS AND METHODS:

The Human Research Protections Office (HPRO) of the University of Maryland, Baltimore, approved this study. The study was determined to be exempt from Institutional Review Board (IRB) evaluation because all data were pre-existing and the subjects were unidentifiable from the data set (submission HP-00067990).

The subjects were retrospectively selected from the records of two private orthodontic offices. The Conventional pre-adjusted appliance, MBT (MacLaughlin, Bennet, and Trevisi) prescription ("twin brackets" manufactured by 3M Unitek Orthodontics Products; Monrovia, USA) with .022- inch slots. The usual arch wire sequence in this office is:

- .014 - .016" NiTi (nickel titanium)
- .018" SS (stainless steel)
- .016 x .022" NiTi
- .018 x .025" SS or .019 x .025" SS

The Damon Q brackets (passive self-ligating- manufactured by Ormco with .022" slot). The usual arch wire sequence in this office is:

- .014" CuNiTi (copper nickel titanium)
- .018" CuNiTi
- .014 x .025" CuNiTi
- .018 x .025" CuNiTi
- .019 x .025 TMA (beta titanium)

The initial pool of subjects included twenty-eight from the Conventional office and twenty-nine from the Damon office (Figure 1).

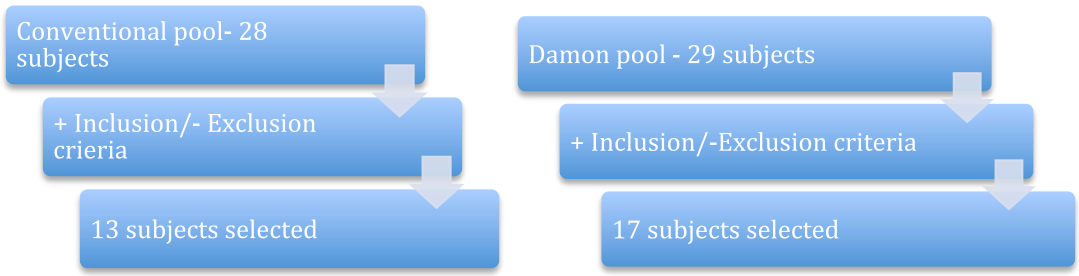


Figure 1: Subjects selection process

Table 1. The selection process in this study is based on the following inclusion and exclusion criteria:

Inclusion criteria:	**Exclusion criteria**:
➢ Non-growing patients, determined to be post-pubertal, CVMS III-V,	➢ Patients prior to pubertal growth spurt,
➢ Class I occlusion or mild Class II or Class III malocclusion	➢ Moderate to severe Class II or III malocclusion
➢ Moderate (5-9mm) to severe (≤9mm) crowding	➢ Extraction treatment
➢ Patients in permanent dentition	➢ Patient with mixed or deciduous dentition
➢ Non-extraction treatment	➢ IPR in excess of 1 mm
➢ Interproximal reduction not to exceed 1 mm	➢ Missing dentition, excluding 2^{nd} and 3^{rd} molars
➢ No therapeutic intervention exclusive of arch wires,	➢ Pathology associated with the head and neck,
➢ No surgical intervention,	➢ Radiation to the head and neck.
➢ Pre and post- treatment CBCT,	➢ Bruxism
➢ No missing dentition, excluding 2^{nd} and third molars	➢ Temporomandibular dysfunction
	➢ Teeth with history of trauma
	➢ Root canal treated teeth

Thirty subjects (n=30) overall were selected in this retrospective study based on the inclusion and exclusion criteria in Table 1. Thirteen (13) were treated with Conventional brackets and seventeen (17) treated with Damon passive-self ligating brackets. The Conventional group had older subjects (9 females and 4 males) with a mean age of 22 years old at T1 CBCT and mean age of 24 years old at T2 CBCT. While the Damon group had younger subjects (10 females and 7 males) with a mean age of 19 years old at T1 CBCT and mean age of 21 years old at T2 CBCT (Table 2). The mean duration of orthodontic treatment for subjects treated with Conventional brackets was 24 months while the Damon group was more at 27 months (about 3 months longer than the conventional group).

Table 2. Brackets, gender, mean age and treatment duration, showing a summary of the bracket system used, mean age at pre-alignment, post-alignment and mean duration of treatment. F= female subjects, M= male subjects.

Bracket (Gender)	Mean age at T1	Mean age T2	Mean Tx duration (months)
Conventional (9F, 4M)	22 y/o	24 y/o	24 mo
Damon (10F, 7M)	19 y/o	21 y/o	27 mo

Measurements were made at two time points (pre-alignment- T1 and post-alignment- T2) on the CBCT images to determine the bone height (BH) changes of 24 buccal surfaces for each subject (n= 720). The buccal root surfaces of maxillary and mandibular central and lateral incisors, canines, first and second premolars and first molars were measured.

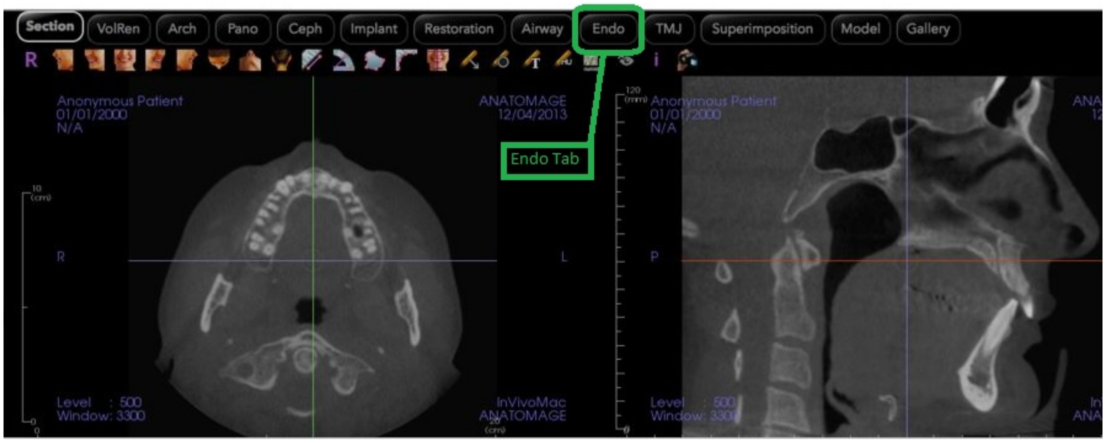
RECORDING PROCEDURES:

Both offices use an i-CAT scanner (Imaging Sciences International, Hatfield, Penn) for CBCT scans. The patients were scanned with a configuration of 0.3 mm volumetric reconstruction, isometric voxels, 120-kVp-tube voltage, field of view (FOV) of 16 cm x 13 cm and 3.8 mA tube current for the Conventional office. The Damon had a configuration of 0.4 mm volumetric reconstruction, isometric voxels, 120-kVp-tube voltage, field of view (FOV) of 16 cm x 13 cm and 3.8 mA tube current. Both groups were scanned for 8.9 seconds during which the machine rotated around the patient one time and exposed the patient to approximately 69 micro-Sieverts of radiation (Ludlow, 2015). The Damon office used a smaller FOV for the post-treatment CBCT. This is a quick scan feature, which scans for 4.8 seconds and does a half rotation to reduce the amount of radiation each patient is exposed to.

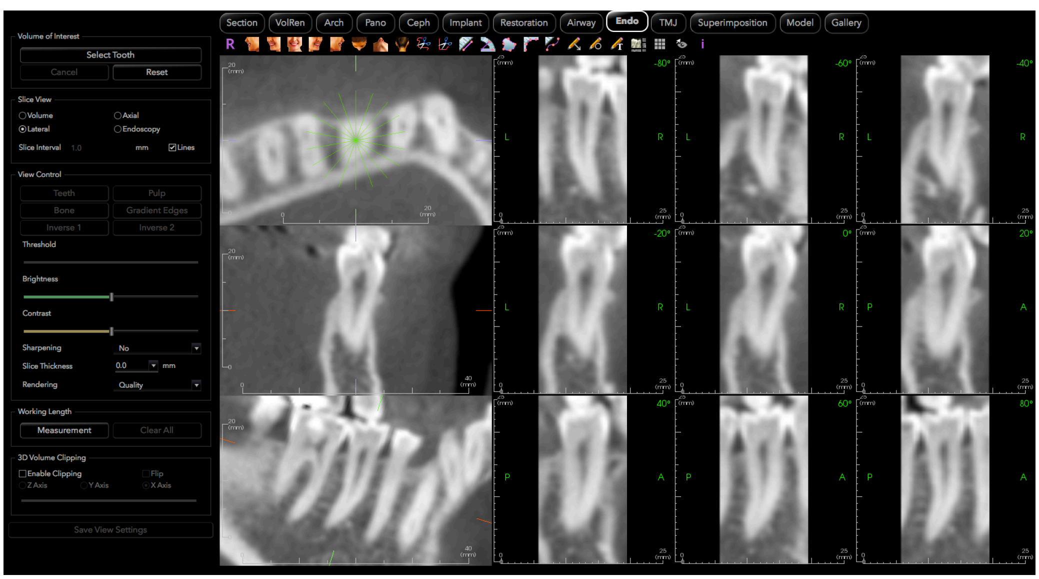
DICOM files were obtained for both the Conventional and Damon groups and the images were analyzed using InVivoMac, Version 6.0.3 software (Anatomage, San Jose, CA) Figure 2.

<u>Figure 2:</u> InVivoMac, Version 6.0.3 software (Anatomage, San Jose, CA)

The images were reformatted and the measurement plane carefully defined using the Endodontic module function (Figure 3) to generate the CBCT image slice in the correct orientation before measurement. To achieve optimal visualization of the marginal alveolar bone crest, first a tooth is selected and placed in the middle of a 3-dimensional (3D) view box which helps to view the tooth in 3 planes of space, the axial, sagittal and coronal planes (Figure 4).



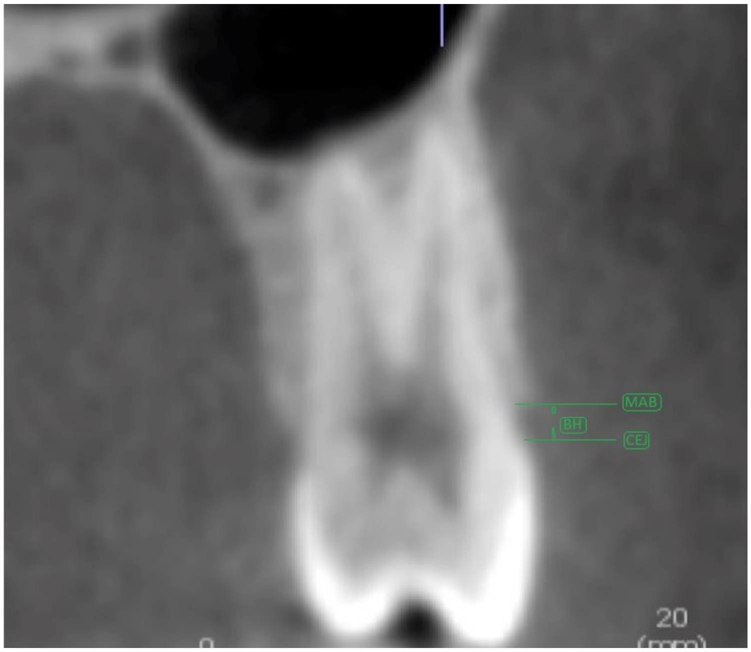
<u>Figure 3:</u> Endo tab function, InVivoMac, Version 6.0.3 software (Anatomage, San Jose, CA)



<u>Figure 4:</u> Reformatted CBCT image using the Endo module, which enables a cross-sectional image of the tooth to be seen. Sagittal view for anterior teeth and coronal section for the posterior teeth InVivoMac, Version 6.0.3 software (Anatomage, San Jose, CA)

Measurements were carried out in the sagittal plane for the anterior teeth and coronal plane for the posterior teeth. When a tooth was selected, orientation is along the longitudinal axis of the tooth (from the tip of the crown to the apex of the root), which coincides with the widest dimension (labio-lingual/ palatal for the anterior teeth and bucco-lingual/ palatal for the posterior teeth) in the axial root section at the CEJ. The view obtained is locked when the pulp chamber can be viewed clearly from the crown to the root section of the tooth. After the image is locked then the buccal alveolar bone height measurement is made. For the maxillary molars a modification was made for proper orientation of the mesiobuccal root. The longitudinal axis along the mesiobuccal root was selected for the maxillary first molars while the longitudinal axis along the mesial root was selected for the mandibular first molars.

Measurements were made on the pre-alignment (T1) and post-alignment (T2) of the CBCT images to determine the buccal alveolar bone height (BH) for each tooth from the CEJ, to the marginal alveolar bone crest (MAB) on the buccal root surface in both maxilla and mandible (Figure 5). In the maxillary arch measurements were made from the upper right maxillary first molar to the upper left maxillary first molar. The mandibular arch included lower right mandibular first molar to the lower left mandibular first molar.



<u>Figure 5:</u> Measurement made from CEJ to MAB on the buccal root surface to obtain BH. InVivoMac, Version 6.0.3 software (Anatomage, San Jose, CA)

<u>Statistical Analysis:</u>

For the assessment of error, Inter-rater reliability was calculated using *Pearson's Correlation co-efficient*. Two evaluators participated in the measurement of alveolar bone changes on the CBCT images. One evaluator carried out the initial measurement of alveolar bone height on all the data, after consultation and agreement with the second evaluator on the parameters and landmarks to be measured. Then six subjects were chosen at random (3- from the Conventional and 3- from the Damon bracket group) and a second evaluator with more experience carried out another set of measurements to be used to determine the inter-rater reliability (the second evaluator is Dr. Jeffery Price, Director of Oral Radiology, University of Maryland Baltimore School of Dentistry). *The Pearson's Correlation Co-efficient* (Table 2) was calculated using the same subjects from the first and second evaluators. The *r* -value was calculated to be 0.97

Table 3. Pearson's Correlation Co-efficient.

1st Evaluator	2nd Evaluator	*r* -value
6 subjects	6 subjects	0.97

To evaluate changes within each treatment group, paired *t*-tests were used to study the effects of -

- Conventional brackets on alveolar bone height
- Damon passive self-ligating brackets on alveolar bone height.

To evaluate and compare the changes in alveolar bone height between the two bracket systems, an independent *t*-test was performed on the differences between T1 and T2 measurements for the Conventional and Damon groups.

RESULTS:

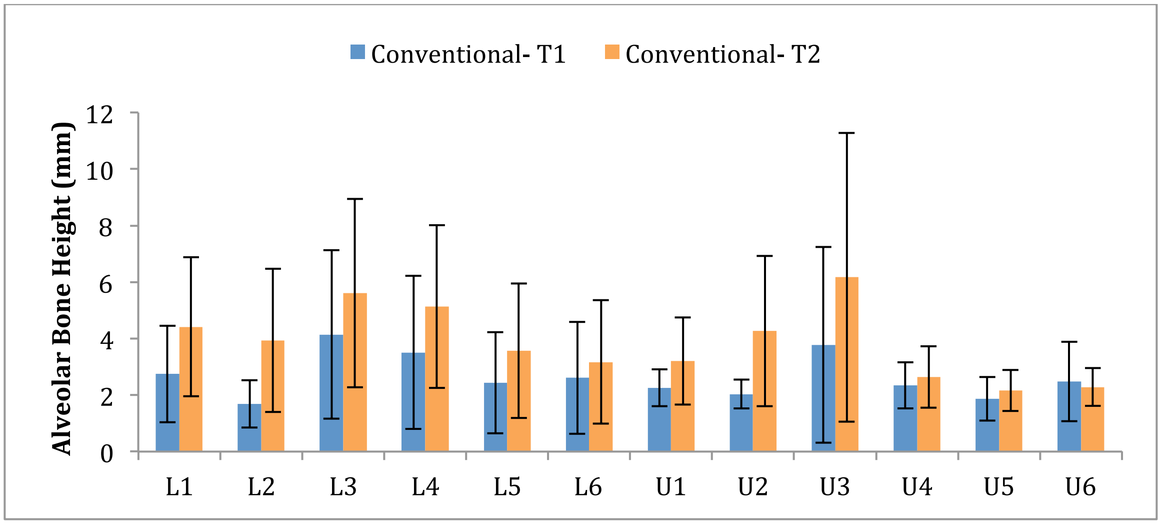
The first hypothesis proposed that there would be a change in alveolar bone height measured on CBCT images between Conventional brackets T1 vs. Conventional brackets T2. Table 4 shows the results of the paired *t*-test comparing Conventional T1 and T2 alveolar bone height changes. Red asterisks indicate significant differences.

Mandible: We observed great variability in the measurements, expressed as the standard deviation in both T1 and T2 measurements (Table 4 & Figure 6). Nonetheless there was a statistically significant decrease found in L1*, L2*, L3* and L4* ($p \leq 0.05$). The greatest variability was found in the L3 and L4, while the greatest percentage of change was found in the L2 and L1 respectively.

Maxilla: We observed great variability in the measurements, expressed as the standard deviation in both T1 and T2 measurements (Table 4 & Figure 6). However there was a statistically significant decrease in U1*, U2* and U3* ($p \leq 0.05$). The greatest variability was found in the U3 and post- treatment U2 respectively. The greatest percentage of change was found in the U2 and U3. The only negative correlation was found in the U6 which showed a -7.65% increase (the change seen here is explained below in the discussion section of this paper).

Table 4. Conventional bracket changes in alveolar bone height T1 and T2. The number of subjects (N) in this treatment group was 13. Teeth measured were the L1-mandibular central incisor, L2- mandibular lateral incisor, L3- mandibular canine, L4- mandibular first premolar, L5- mandibular second premolar, L6- mandibular first molar. First time point (T1) = pre-alignment, second time point (T2) = post-alignment, SD- standard deviation, statistically significant p- value ≤ 0.05 are indicated with a red asterisk.

Conventional group. N=13			
Teeth	T1 Mean (SD)	T2 Mean (SD)	% Change
L1*	2.75 (1.71)	4.41 (2.46)	60.63
L2*	1.69 (0.84)	3.94 (2.54)	132.92
L3*	4.14 (2.98)	5.6 (3.33)	35.17
L4*	3.51 (2.71)	5.14 (2.89)	46.34
L5	2.43 (1.78)	3.57 (2.38)	46.84
L6	2.61 (1.98)	3.17 (2.18)	21.32
U1*	2.26 (0.66)	3.21 (1.55)	41.51
U2*	2.04 (0.52)	4.27 (2.66)	109.46
U3*	3.78 (3.46)	6.17 (5.11)	63.31
U4	2.35 (0.82)	2.64 (1.09)	12.62
U5	1.86 (0.77)	2.16 (0.73)	15.73
U6	2.48 (1.4)	2.29 (0.67)	-7.65



<u>Figure 6</u>. Conventional bracket changes T1 vs. T2, bar graph of mean tooth values (*y-axis*) at T1 (pre-alignment, blue) and T2 (post-alignment, orange) variables. Measurements are expressed in millimeters (*x- axis*), with a standard deviation within each bar.

The second hypothesis proposed that there would be a change in the alveolar bone height measured on CBCT images between Damon passive-self ligating brackets T1 vs. Damon passive-self ligating brackets T2. Table 5 shows the result of the paired *t*-test comparing T1 and T2 alveolar bone height changes. Red asterisks indicate significant differences.

Mandible: We observed great variability in the measurements, which is expressed as the standard deviation in both T1 and T2 measurements (Table 5 & Figure 7). However there was a statistically significant decrease in alveolar bone height for all teeth: L1*, L2*, L3*, L4*, L5*, L6* ($p \leq 0.05$). The greatest variability was found in T1 of L3 and T2 of L2. The greatest percentage decrease was found in the L2 and L5 respectively.

Maxilla: We observed great variability in the measurements, expressed as the standard deviation in both T1 and T2 measurements (Table 5 & Figure 7). Nonetheless there was a decrease in alveolar bone height from T1 to T2 for all the maxillary teeth measured U1-U6. Statistically significant decrease was found in U1* and U4* ($p \leq 0.05$). The greatest variability was found in T1 of U2 and T2 of U4 respectively. The greatest percentage of decrease was found in the U2 and U4. There was some decrease in the U2, U3, U5 and U6 but this was found not to be statistically significant.

Table 5. Damon bracket changes in alveolar bone height T1 and T2. The number of subjects (N) in this treatment group was 17. L1-mandibular central incisor, L2-mandibular lateral incisor, L3- mandibular canine, L4- mandibular first premolar, L5-mandibular second premolar, L6- mandibular first molar. First time point (T1) = pre-alignment, second time point (T2) = post- alignment, SD- standard deviation, statistically significant p- value ≤ 0.05 in red asterisk.

Damon group. N=17			
Teeth	T1 Mean (SD)	T2 (SD)	% Change
L1*	2.79 (1.78)	5.12 (3.06)	82.75
L2*	2.35 (1.47)	5.43 (3.44)	131.24
L3*	3.78 (2.41)	6.31 (3.07)	66.78
L4*	4.08 (2.32)	6.05 (2.29)	48.21
L5*	2.29 (1.22)	4.62 (2.43)	101.3
L6*	1.81 (0.84)	2.89 (1.46)	59.85
U1*	2.12 (0.73)	3.21 (1.87)	51.38
U2	2.63 (2.11)	4.16 (2.87)	57.91
U3	3.05 (2.09)	4.1 (2.33)	34.53
U4*	2.59 (2.09)	3.89 (3.02)	50.16
U5	1.59 (0.62)	1.99 (0.82)	24.88
U6	2.19 (1.15)	2.42 (1.05)	10.44

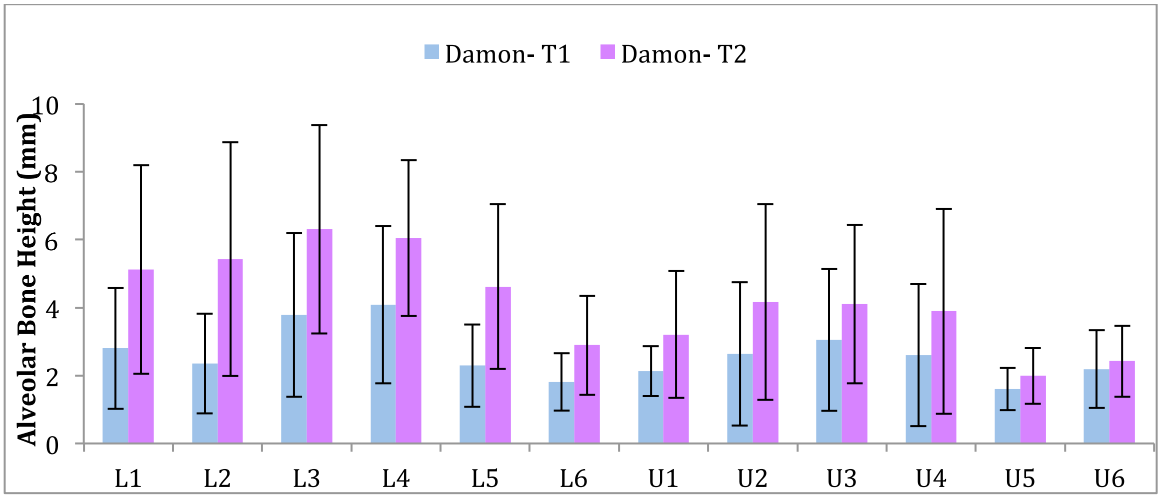
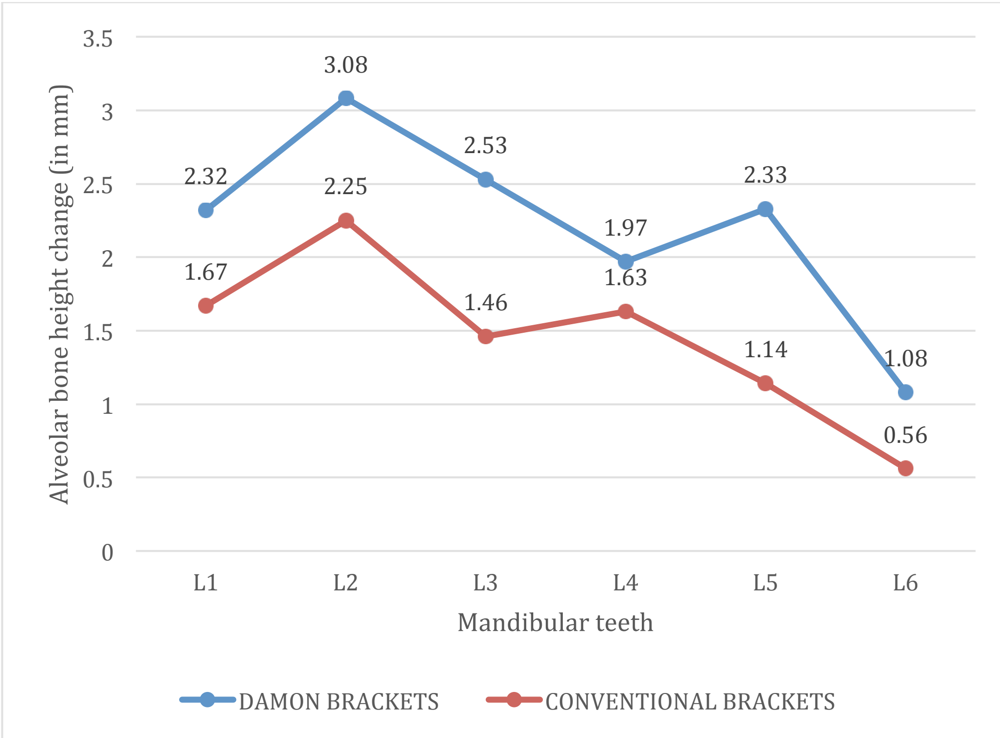


Figure 7. Damon bracket changes T1 vs. T2, bar graph of mean tooth values (*y-axis*) at T1 (pre-alignment, blue) and T2 (post-alignment, purple) variables. Measurements expressed in millimeters (*x- axis*), with the standard deviation within each bar.

The third hypothesis proposed that alveolar bone height change would be greater for the Damon group than the Conventional group**.** To determine if the Damon group had a greater alveolar bone height decrease than the Conventional group, Independent *t*-tests were performed. Results are shown in Tables 6 and 7 also Figures 8 and 9. There was no statistically significant difference between the Conventional and the Damon groups, even though on average the Damon group showed more alveolar bone height decrease between T1and T2 than the Conventional group.

<u>Table 6</u>. Independent t-tests performed on the mandibular alveolar bone height differences for both Conventional and Damon groups. L1-mandibular central incisor, L2-mandibular lateral incisor, L3- mandibular canine, L4- mandibular first premolar, L5-mandibular second premolar, L6- mandibular first molar. There was no statistically significant difference (p- value ≤ 0.05).

Teeth (mandibular)	CONVENTIONAL BRACKETS (SD)	DAMON BRACKETS (SD)
L1	1.67 (1.91)	2.32 (2.75)
L2	2.25 (2.45)	3.08 (3.59)
L3	1.46 (2.36)	2.53 (2.64)
L4	1.63 (2.75)	1.97 (2.50)
L5	1.14 (2.17)	2.33 (2.02)
L6	0.56 (2.34)	1.08 (1.52)



<u>Figure 8</u>. Straight marked scatter graph of independent *t*-test to compare Conventional vs. Damon change in the mandible, alveolar bone height difference on the *y-axis* and mandibular teeth on *x- axis*.

<u>Table 7</u>. Independent *t*-test performed on the maxillary alveolar bone height difference for both Conventional and Damon groups. U1-maxillary central incisor, U2- maxillary lateral incisor, U3- maxillary canine, U4- maxillary first premolar, U5- maxillary second premolar, U6- maxillary first molar. There was no statistically significant difference (p-value ≤ 0.05).

Teeth (maxillary)	CONVENTIONAL BRACKETS (SD)	DAMON BRACKETS (SD)
U1	0.94 (1.48)	1.09 (1.56)
U2	2.23 (2.64)	1.53 (3.10)
U3	2.39 (2.55)	1.05 (2.32)
U4	0.30 (1.14)	1.30 (2.50)
U5	0.29 (1.03)	0.40 (0.80)
U6	*-0.20 (1.22)	0.23 (0.68)

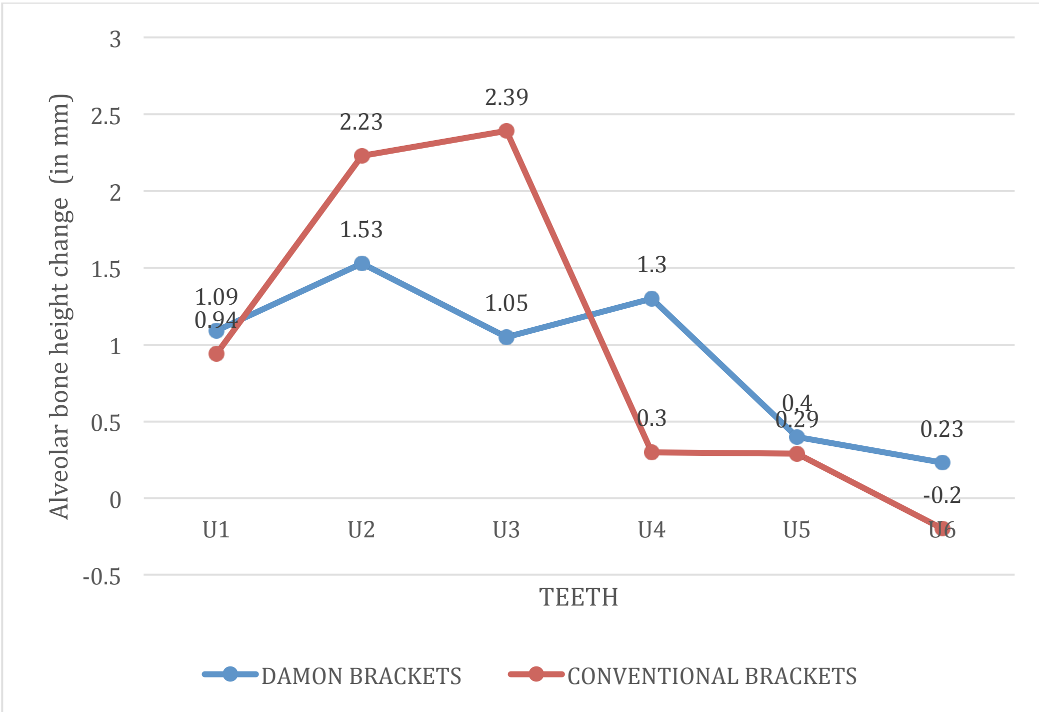


Figure 9. Straight marked scatter graph of independent *t*-tests to compare Conventional vs. Damon change in the maxilla, alveolar bone height difference on the *y-axis* and maxillary teeth on *x- axis*.

DISCUSSION:

CBCT images have been shown through previous studies to have high specificity and sensitivity to measure buccal alveolar bone height with accuracy (Leung et al, 2010). It can be used to quantitatively assess bone height with great reliability (Timock et al, 2011). The high definition and sensitivity of CBCT images ensure that the buccal cortical bone and teeth are visualized without any overlapping, making it possible to measure decreases in buccal alveolar bone height as a result of orthodontic tooth movement (Castro et al, 2016).

Earlier findings have shown that there are naturally occurring defects in the alveolar bone height, although in the healthy situation, the alveolar crest is slightly apical to the CEJ by approximately 1.5- 2 mm (Nanci, 2013). The alveolar crests of neighboring teeth are also uniform in height along the jaw in the healthy situation (Bath-Balogh et al, 2011). Dehiscence and fenestrations (abnormal decrease and loss of alveolar bone) have been found to be a common occurrence in modern American skulls. In a study by Rupprecht et al, 2001, one hundred and forty six American skulls was collected from the Robert J. Terry Collection of the National Museum of Natural History, Washington DC. The collection was assembled from 1920-1958. These subjects had a mean age of 49.1 years. The prevalence of dehiscence was found to be in 40.4% of the skulls and the most common site for this was the mandibular canine (12.9%). In the same study fenestrations was present in 61.6% of the skulls and the most common site for this was the maxillary first molar (58%). In a similar study from China, Zhou et al, 2015 evaluated the alveolar bone defect on the anterior region in patients with bimaxillary protrusion using CBCT. This study had 50 subjects who were divided into the adult group (mean age- 22.9 years) and the teenage group (mean age 13.1 years). The prevalence of dehiscence was found to be 42.46% in the adult group and 30.13% in the teenage group. In both groups dehiscence was found to be greater in the mandible. Fenestrations were greater in the maxilla with no significant difference between the adult and teenage groups. The similarity in these findings show that there are naturally occurring abnormal decreases in alveolar bone height > 2 mm (dehiscence), in these populations (American and Chinese). In adults, prevalence of dehiscence is 40.4- 42.46 % and the most common site for this is the mandible (canine), while in children the prevalence of abnormal decrease in alveolar bone height is 30.13% and the most common site is also the mandible.

Gingival recession as earlier stated is an undesirable condition resulting in root exposure (Kassab et al, 2003). An important etiologic factor associated with gingival recession is a prior lack of alveolar bone at these sites (dehiscence and fenestrations of the alveolar bone). Orthodontic movement of teeth outside the labial or lingual alveolar plate leading to formation of dehiscence has been shown to be a significant cause of physiologic gingival recession. A potential side effect of labial orthodontic tooth movement on the alveolus has previously been demonstrated in animal studies (Wennstrom, 1987). This resulted in apical displacement of the gingival margin and obvious gingival inflammation. A surgical study found a positive correlation between gingival recession and bone dehiscence (Kassab et al, 2003). Hence, the assessment of a bony covering is critical when planning any tooth movement, since it has been demonstrated that excessive sagittal or transverse movements or tipping can result in the teeth being moved outside the alveolar bone housing, which causes dehiscence of buccal alveolar bone, root exposure and ultimately leads to recession of the gingival margin, poor esthetics, root sensitivity, development of root caries and potential loss of tooth. This same study found the prevalence of gingival recession to be in more than 50% of the population with one or more sites of 1 mm or more. Gingival recession has been found in patients with good and poor oral hygiene. It has been proposed that recession is multifactorial. Recession is found to occur more frequently on the buccal surface than any other aspects of the teeth (Kassab et al, 2003).

This study found that there was an overall decrease in the labial (anterior teeth), and buccal (posterior teeth) alveolar bone height regardless of the bracket system (Conventional or Damon) used in the orthodontic offices except on the maxillary first molars in the Conventional group which showed a measurement increase of 0.19 mm (7.65%) in the buccal alveolar bone height. The reason for this is possibly because the mesiobuccal root of the first molar was repositioned (submerged) in the alveolar bone, and not that there was a net increase (growth) in the alveolar bone. The over all decrease in the buccal alveolar bone height was found to be 48% in the Conventional group and 60% in the Damon group. Results observed by Castro et al 2016, who conducted comparable studies found a 75% decrease (the type of bracket used for the subjects in this study was not stated), while Lund et al 2012, using Conventional brackets found an 85% decrease in subjects that required premolar extractions as part of their orthodontic treatment. Garlock et al 2016, using Damon Q brackets also observed a mean of 1.16 +/- 2.26 mm bone recession on the facial alveolar bone surfaces of patients treated by nonextraction with Damon brackets.

Figure 13, which compares the changes in the maxillary teeth between subjects, treated with Conventional and Damon brackets supports the Damon philosophy in that there was more expansion (decrease in BH) in the posterior areas of the upper first premolar and second premolar areas while keeping the upper incisors in position with minimal change upholding the theory about the "Frankel" and "Lip competency" effects.

Additionally, this study observed statistically significant differences in the CBCT images between T1 and T2 buccal alveolar bone height of some teeth. The Conventional group showed statistically significant decrease in 4 mandibular teeth- the central, lateral, canine and first premolar and in the maxilla 3 teeth showed statistically significant decrease- the central, lateral and canine. The Damon group showed a statistically significant decrease in all the teeth in the mandible- the central, lateral, canine, first premolar, second premolar and molar and in the maxilla 2 teeth- the central and first premolars. This pattern of decrease observed highlights the point that for both Conventional and Damon treated subjects, there appears to be more alveolar bone decrease in the mandible than in the maxilla. This gives orthodontic practitioners an insight that when treating patients with crowding with any bracket system non-extraction, the mandible is more susceptible to develop decreases in alveolar bone height which may lead to periodontal defects (dehiscence and gingival recession), while the anterior maxilla is the site most susceptible to develop decreases in alveolar bone height. The reason for this may be that the mandible is made up of more dense cortical bone that is less forgiving of teeth movement than the maxilla, which is made up of more cancellous (spongy) bone. It is worthy to note that with excessive tipping of the teeth buccally or labially, the alveolar bone may not necessarily follow the roots of the teeth as it is pushed out of bone. Alveolar bone crest bending has been seen in humans with forces less than 50g and can account for 0.6- 25% of orthodontic tooth movement (Grimm, 1972).

The largest decrease in buccal alveolar bone height for the Conventional group was observed in the mandibular lateral incisor and maxillary lateral incisor area. The Damon group showed the largest decrease in the mandibular lateral incisor and maxillary central incisor respectively. These results echo observations by previous authors who observed dehiscences on labial surfaces of mandibular anterior teeth particularly because these surfaces have thinner cortical bone and less marrow (Castro et al, 2016). Predictors for dehiscence include occlusal attrition, root prominence and alveolar bone thickness. The sole predictor of dehiscence was lack of attrition. The presence of dehiscence and fenestrations were positively correlated with thin alveolar bone and negatively correlated with occlusal attrition (Rupprecht, 2001). It is also important to note that naturally occurring dehiscence occurs in 40.4- 42.46 % of adult and 30.13% in children. While more than 50% of the patients that come in for orthodontic treatment already have gingival recession of 1 mm or more in one or more sites.

The recommended voxel sizes for diagnostic orthodontic procedures are 0.3 mm and 0.4 mm respectively. These provide lower spatial resolution than smaller voxel sizes and should be used with caution if the goal is to assess small variations in bone thickness. A smaller voxel size would be more appropriate for these studies (Molen, 2010). Computed tomography (CT) has been described as the best and most reliable diagnostic imaging method that provides three-dimensional quantitative assessment of buccal and lingual bones (Fuhrmann, 2002), but it is expensive and results in higher radiation dose than CBCT. CBCT is better for routine orthodontic diagnosis and treatment planning. It is less expensive than routine CT and results in less radiation. The high accuracy of CBCT for the diagnosis and quantitative analysis of the level of buccal and lingual alveolar bone crest was confirmed (Enhos, 2012). CBCT has the advantage of generating 3-D images and has replaced conventional film-based or digital 2D radiography as the standard for most clinical and research examination of oral hard tissues.

Limitations of study

This study had some limitations. First, the high variability in the measurement of alveolar bone height may be due to a small sample size. In this study we had thirty subjects who were not matched for age and previous periodontal conditions before orthodontic treatment.

Second, it did not take into consideration other factors, which might have affected the duration of treatment such as office treatment protocol, time span between, appointments number of broken brackets, missed appointments and patient compliance in either of the groups. Clearly if these events had occurred in any of the groups, it would have added to the treatment duration. This may be the reason why the (younger) Damon group showed longer treatment duration than the (older) Conventional group. Advocates of the Damon philosophy affirm that treatment with these brackets ought to be faster because the technique applies passive self-ligating brackets that use low force and less friction to move the teeth faster.

A third limitation is that the difference in the voxel size of the Conventional (0.3 mm) and Damon group (0.4 mm) may have decreased the apparent alveolar bone height difference in the Damon group even further (false-positive) than it truly is. This may be the reason why the Damon group showed an overall greater decrease in alveolar bone height than the Conventional group, even though this was not statistically significant.

A final limitation is how long after debond the data are collected. Earlier studies suggested to take the post-treatment CBCT image at least 1 year after debond to allow for marginal alveolar bone to re-mature after the effect of regional acceleratory phenomenon (RAP- takes about 6-24 months to fully subside after orthodontic treatment). When teeth are being moved orthodontically, the alveolar bone in the direction in which they are being moved will undergo constant bone turnover, which is driven by the activity of osteoclasts. This increase in osteoclastic activity and reduction in alveolar bone density is called RAP (Molen, 2010). Subjects in this study had their post treatment CBCT taken after alignment of the teeth, which may have overestimated the reduction in alveolar bone height due to orthodontics treatment. However the percent change in bone height in this study (48% and 60%) is smaller than the percent change in other studies (75%- Castro et al, 2016, 80% Lund et al, 2012) suggesting that the early recording time may not have been a problem.

A larger sample size could help to narrow down the pattern of alveolar bone height decrease, in this study there were thirty subjects and we saw great variability in the bone height measurements and correctly match the subjects for age and periodontal conditions before orthodontic treatment. To determine and compare the duration of treatment, future studies should take into consideration those factors (office treatment protocol, time span between appointments number of broken brackets, missed appointments and patient compliance) that tend to extend treatment time and control for these during data collection. The same voxel size for CBCT imaging will ensure that a consistent resolution was used in the imaging technique.. Delaying the final CBCT image till about a year after debond will ensure that the marginal alveolar bone would have re-matured and potentially eliminate the effect of RAP. Future prospective studies may be required that account for these limitations during the development of the research method. Lastly, a study can be designed to measure the rate of osteoplastic/ osteoplastic remodeling during orthodontic treatment using CBCT.

Hypothesis supported and rejected

The results obtained from this study, supported hypothesis I. There was a decrease in alveolar bone height measured on CBCT images between Conventional brackets pre-treatment vs. Conventional brackets post-treatment.

Hypothesis II was also supported by this result of this study, there was be a decrease in the alveolar bone height measured on CBCT images between Damon passive-self ligating brackets pre-treatment vs. Damon passive-self ligating brackets post-treatment.

Hypothesis III which stated that, alveolar bone height decrease would be greater for the Damon group than the Conventional group was rejected by these results. There was no significant decrease in alveolar bone height between subjects treated with Conventional vs. Damon brackets.

The goals at the beginning of this study have been met because we have been able to:

Goal 1) Determine how much decrease in buccal alveolar bone height occurs on CBCT images T1vs. T2 with Conventional brackets.

Goal 2) Determine how much decrease in buccal alveolar bone height occurs on CBCT images T1 vs. T2 with Damon brackets.

Goal 3) Determine that there is no statistically significant decrease in the alveolar bone height in subjects treated with either of these brackets.

CONCLUSIONS:

There was a change (decrease) in alveolar bone height after orthodontic treatment with both Conventional and Damon brackets. However these changes do not appear to be statistically significant when comparing the two treatment groups.

When treating patients with crowding with any bracket system nonextraction, the mandible is more susceptible to develop decreases in alveolar bone height, which may lead to periodontal defects (dehiscence and fenestration) and the anterior maxilla is the site most susceptible to develop decreases in alveolar bone height in this study.

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