ASSOCIATION BETWEEN ALVEOLAR BONE WIDTH AND POST-ORTHODONTIC TOOTH MOVEMENT

By

LUCAS D. MCGUIRE, D.M.D.

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Thesis Committee

Thesis Advisor: Manish Valiathan M.D.S., D.D.S., M.S.D.

J. Martin Palomo D.D.S., M.S.D.

Mark G. Hans D.D.S., M.S.D.

Sena Narendran D.D.S., M.Sc., D.D.P.H.

CASE WESTERN RESERVE UNIVERSITY

SCHOOL OF DENTAL MEDICINE

DEPARTMENT OF ORTHODONTICS

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Estimating the Association between Alveolar Bone Width and Post-Orthodontic Tooth Movement

Abstract

By

Lucas D. McGuire, DMD

Objective: The aim of the study was to investigate any association between bone width surrounding mandibular incisors and post-orthodontic tooth movements. **Methods**: The study sample consisted of 16 males and 30 females with an average age of 13.4 ± 1.7 years before orthodontic treatment (T_0), 15.5 ± 1.7 years after treatment (T_1), and 17.0 ± 2.3 years at least six months after treatment (T_2). Using Dolphin's imaging software interproximal, labial, and lingual bone thickness was measured on cone beam computed tomography scans. Crowding and intercanine width were measured on dental casts. **Results**: Tooth movement at T_2 was less than 1mm for 39 subjects and more than 1mm for 7 subjects. The bone width increased between T_0 to T_1 by 0.44 ± 0.47mm between the incisors, decreased 0.07 ± 0.29mm labially, and decreased 0.69 ± 0.68mm lingually. **Conclusions**: There was no association between bone width surrounding mandibular incisors and post-orthodontic changes.

INTRODUCTION

Stability and relapse of the dentition following orthodontic treatment has been an area of interest for orthodontists, who for decades have attempted to quantify mandibular incisor alignment. One of the most popular techniques, Little's irregularity index (1975), measures the linear displacement of the anatomic contact points of each mandibular incisor. The sum of the five displacements represents the degree of mandibular incisor irregularity. Although this index has been quite useful in quantifying post-orthodontic changes of the dentition, the author still believes that "the degree of crowding that develops after retention is variable and unpredictable" (Little 1999).

Sinclair and Little (1983, 1985) studied the changes during maturation of untreated normal occlusions to determine the nature of the developmental process. Results showed a decrease in total arch length and intercanine width, which may be linked to increases in mandibular incisor irregularity. The researchers could not determine though, associations with or predictors of lower anterior irregularity. Eslambolchi et al. (2008) corroborated Sinclair's conclusions, stressing the importance of retention to avoid late developmental crowding. The question of etiology of post-treatment changes remains. Proposed causes under the control of the orthodontist include periodontal and occlusal factors. Other causes of relapse which are considered out of the control of the orthodontist include soft tissue changes and

late growth changes, specifically mandibular growth. Both of these changes are part of the normal aging process (Blake and Bibby 1998).

Retention in orthodontics is based heavily on practitioner preference, experience, and ease of use. The decision to prescribe a specific type of retainer is not always based on science. In 1919, Charles Hawley designed his famous retainer that remains very popular among practitioners even today. At a local meeting of orthodontists at that time, Hawley was asked how often to wear removable retainers. He responded with "Oh, I don't know, six months full, six months part time" (Littlewood et al. 2006). To this day, that regime remains one of the most common for orthodontists worldwide.

Mandibular anterior crowding during the post-treatment phase of orthodontics continues well into the fourth or fifth decade of life, and therefore stability of the dentition is important (Uhde et al. 1983, Puneky et al. 1984). Some practitioners recommend fixed retention of the mandibular incisors to avoid post-treatment orthodontic changes. Good alignment between the mandibular incisors can be maintained, but oral hygiene and periodontal health could be compromised by this approach (Sadowsky et al. 1994).

Other methods of avoiding post-treatment changes have been proposed, including fiberotomy, interproximal reduction of enamel, and maintenance of the pre-treatment incisor position (Blake and Bibby 1998). There has been no consensus on how to avoid post-orthodontic tooth movement, even though it has been studied

extensively. Studying the bone width between mandibular incisors and its possible association with post-treatment changes could shed some insight on this complex problem in orthodontics.

The aim of this study is to determine the degree of association between the bone width surrounding mandibular incisors and post-orthodontic tooth movements. Long-term stability is an important focus in orthodontics, as every orthodontist recommends long-term retention of corrected tooth alignment. Is there an association between alveolar bone width surrounding mandibular incisors and post-orthodontic tooth movement?

LITERATURE REVIEW

Stability and relapse of the dentition following orthodontic treatment has been an area of interest for orthodontists, who for decades have attempted to quantify mandibular incisor alignment. One of the most popular techniques, Little's irregularity index, was described in 1975 and measures the linear displacement of the anatomic contact points of each mandibular incisor. The sum of these five displacements represents the degree of mandibular incisor irregularity (Little 1975). Although this index has been quite useful in quantifying post-orthodontic changes of the dentition, according to the University of Washington studies in 1999, "the degree of crowding that develops after retention is variable and unpredictable" (Little 1999). The question of how to avoid the post-orthodontic movement remains.

Contributing factors to stability of the dentition have been discussed for over a hundred years. Kingsley, in *A Treatise on Oral Deformities as a Branch of Mechanical Surgery* (1880), suggested that the occlusion is the key to long-term stability. He suggested that if the dentition were in the proper cusp and embrasure relationship following orthodontic treatment, it would remain stable. This thought process was very popular at that time, but this predated the routine use of retainers.

Rogers (1922) put a different theory forth when he attributed stability of the dentition to harmonious muscular balance. The major factor in the etiology of malocclusion is the strong muscle pressure exerted against the easily adaptable

dentition. He suggested that muscular training should be done concurrently with orthodontic mechanics to relieve the muscular pressure and achieve a stable overall result. If these muscular exercises are done properly retention should be very simple and in most cases unnecessary unless the muscular pressure is too difficult to overcome.

Around the same time as Rogers, Lundstrom (1923) discussed the importance of the apical base in establishing stability. He believed that the mandibular incisors should be aligned over the basal bone of the mandible to best disperse the forces of occlusion. To this extent, the mandibular incisors should not be excessively proclined or retroclined, which are both unstable positions. At the proper alignment over basal bone, the mandibular incisors should remain stable with minimal retention.

Charles Tweed in 1941 came to a similar conclusion as his predecessor nearly twenty years later. He published a paper discussing the importance of the position of the mandibular incisor based on his own patients with esthetically pleasing faces. Tweed's goal was to achieve or conserve an incisor to mandibular plane angle (IMPA) of 90 degrees plus or minus five degrees at the end of treatment. This angulation attempts to center the incisor within basal bone to gain stability. Margolis, in 1943, evaluated models, radiographs, photograhs, and dry skulls of treated and untreated subjects and concluded that the best results are achieved when the mandibular incisors form a right angle with the mandibular plane, agreeing with Tweed's findings.

Another important variable for establishing stability is to maintain mandibular intercanine width. Several studies have correlated expansion of the intercanine width with incisor irregularity post-treatment (Strang 1949, Steadman 1961, Little et al. 1988, Artun et al. 1990, Vaden et al. 1997, Burke et al. 1998, Housley et al. 2003, Dyer et al. 2012, Myser et al. 2013). Little and coworkers (1988) assessed the records of thirty-one patients treated with premolar extractions. One factor that was consistent for all of the patients studied was the decrease in mandibular intercanine width. It was concluded that any increase in intercanine width through orthodontic treatment subsequently decreases toward the pre-treatment width, but an explanation as to why this occurred was lacking. It was recommended that the only way to "ensure continued satisfactory alignment posttreatment" is to use retention for life, either fixed or removable. This conclusion may be somewhat grandiose due to several limitations in the study. There was a small sample size in the study limited to cases with premolar extractions. Furthermore, only the irregularity index was used to quantify post-treatment changes with no definition of acceptable or unacceptable results. Due to these restrictions in the study, it is difficult to reach the conclusion that lifelong retention is necessary to guarantee long-term stability.

In 1983, Udhe, Sadowsky, and BeGole assessed seventy-two patients treated with orthodontics twelve to thirty-five years previously. Their findings showed that the intercanine width in the mandibular arch decreased to or further past the pre-treatment intercanine width in all of the patients studied. When comparing post-treatment changes, mandibular intercanine width was associated the most with post-

treatment mandibular crowding. They came to the conclusion that the intercanine width should not be changed and this width should guide the correction of the maxillary arch. There was no explanation or theory as to why the intercanine width should be maintained. They believe that mandibular anterior crowding during the post-treatment phase of orthodontics continues well into the fourth or fifth decade of life and trends toward pre-treatment values. They also concluded that there is no definitive way of distinguishing between normal changes due to latent growth or actual dental relapse.

Maintenance of the pre-treatment arch form to improve stability has also been studied. In 1995, De La Cruz et al. assessed diagnostic records for 87 patients. These records included pre-treatment, post-treatment, and ten years after active treatment. All cases were treated with maxillary and mandibular first premolar extractions. Computer generated arch forms were used to study the changes in arch shape before and after treatment. Results of this study showed that even when efforts were made to maintain the original arch form, the majority of the arches became more round after treatment. Overall, 64% of Class II arches and 69% of Class I arches returned to the pre-treatment shape. The greatest amount of change during treatment showed the greatest amount of post-treatment relapse. It was suggested that the patient's pre-treatment arch form might be the best guide to future arch form stability, but several cases did not remain stable even after maintenance of the arch form. The authors noted a great deal of variability and concluded that the pre-treatment arch form appears to be important but does not necessarily guarantee post-orthodontic stability.

A major limitation to this study is that all subjects were treated with premolar extractions. This could have been the reason for the change in arch form during treatment and account for the variability seen in the study. A second group of subjects treated through non-extraction for comparison could have improved the impact of the study.

Which factors could predispose a patient to post-orthodontic changes? Periodontal factors appear to have a strong influence on the susceptibility of a tooth to relapse. Reitan (1959) studied periodontal fibers and rotation of teeth in young dogs. Most of the periodontal fibers are attached from the root to the inner surface of the alveolus and are called principal fibers. There is another group of fibers, called free gingival fibers that are attached within gingival soft tissues. Reitan showed in histological sections that periodontal fibers attaching from alveolar bone to the root surface are rearranged within 28 days. However, the gingival and supra-alveolar fibers are only partially rearranged after eight months. He believed that relapse was caused by the contraction of these displaced gingival fibers. He recommended overcorrection of rotated teeth to protect against relapse. Reitan also encouraged early correction of rotated teeth so that more time is allowed for rearrangement of the periodontal, especially gingival, fibers.

Reitan followed up his initial work in 1969 and further discovered that 6% of the gingival and supra-alveolar fibers are oxytalan and elastic fibers. These fibers increase in thickness and strength as a result of stretching and function. There is a

slower turnover of the gingival fibers than principal fibers because of a lack of new cells capable of rearranging the fibers. If force is rapidly discontinued on a tooth after movement without any form of retention, the memory of the periodontal fibers could be enough force to move the tooth to its initial position. Even after two to three months, there is a tendency for the gingival fibers to further contract and relapse could occur. He suggested that removal of the supra-alveolar and gingival fibers could decrease the tendency of a tooth to relapse. This procedure became known subsequently as supracrestal fiberotomy.

Edwards (1970) described the surgical procedure of the supracrestal fiberotomy and brought it into popularity. His initial study consisted of twelve teen-aged patients and sixteen experimental teeth. After rotation of the tooth was completed and retained mechanically for eight weeks, the supracrestal fiberotomy was completed and a dressing placed for one week. The degree of rotation was recorded after three months with no mechanical retention during this time. He found that "negligible rotational relapse occurred" after the three months. It was concluded that this surgical procedure was clinically successful in reducing the relapse of rotated teeth. The limitation of this study was the short observation period of three months.

In the mid-1970s, a national survey was distributed to determine how many orthodontists prescribe supracrestal fiberotomy procedures for their patients. It was determined that one-quarter of orthodontists in the United States prescribed the procedure. These orthodontists agreed that it was effective in reducing rotational

relapse. It was believed that this technique was "reasonably problem-free" and its use will increase in the future (Kaplan 1976).

Edwards (1988) evaluated the long-term effectiveness of the fiberotomy procedure years after it was completed. A total of 320 patients were included in this prospective study, 160 cases and 160 controls. Two time periods were studied, four to six and thirteen to fifteen years after active treatment. It was determined that the procedure was more effective four to six years after active treatment than thirteen to fifteen years after treatment. Also, at both time periods, the procedure was the least effective for the mandibular anterior region. This was attributed to the more complex and multifactorial nature of the anterior dentition in the mandible. It was concluded that the fiberotomy procedure should be used as an adjunct to other forms of retention and demonstrates the difficulty of dealing with this area of the mandibular arch.

The supracrestal fiberotomy procedure has fallen out of favor presently. Current research suggests that the relapse may not be due to the stretching of gingival collagen fibers. After rotation followed by retention, electron microscopy revealed that the fibers were torn, ripped, and disorganized. Additionally, there were an increased number of elastic fibers in the area of the torn fibers. Similar to controls, most fibers quickly returned to an organized pattern of bundles following the gingival fiberotomy. Rotational relapse may be more due to the elastic properties of the gingival tissue rather than stretched collagen fibers (Redlich et al. 1996).

Another potential cause of post-orthodontic change that is under the control of the orthodontist is the occlusion. Melrose and Millett (1998) express that proper interdigitation of the teeth prevents tooth migration and enhances overall stability, but evidence for this statement is lacking. Post-treatment growth may alter this dental relationship, so stability is not guaranteed. Additional occlusal factors that have been suggested as etiologies for relapse include inadequate cusp-fossa relationships, heavy contacts on specific teeth, and the shape of the mandibular incisors (Blake and Bibby 1998).

Peck and Peck (1972) studied two groups of Caucasian females to determine the ideal dimensions of the mandibular incisors. One group consisted of forty-five subjects with perfect alignment of the mandibular incisors, and the other group was seventy subjects used as a control. It was determined that the group with perfectly aligned mandibular incisors had characteristic crown shape ratios, specifically the mesio-distal to facio-lingual ratio. The ideal ratio was determined to be 88.4 for central incisors and 90.4 for lateral incisors. It was concluded that this ratio could lead to long-term stability of these teeth. Although the sample size was small, the authors recommended interproximal reduction of the mandibular incisors to a specific ratio faciolingual and mesiodistal to increase long-term stability.

In 1984, Puneky, Sadowsky, and BeGole evaluated seventy-seven treated patients to determine if the dimensions of the mandibular incisors described by Peck and Peck contributed to the stability of alignment after treatment. It was determined

that incisor dimensions only contributed 7.4% to the post-treatment alignment, which was not statistically significant. This was similar to the control group of eighty-seven subjects, where only 9.1% of the irregularity could be attributed to incisor dimensions. Accordingly, the authors concluded that the size and shape of the mandibular incisors was not a reliable predictor of stability or relapse.

Recent research by Myser and coworkers in 2013 attempted to determine if orthodontic treatment is intrinsically unstable. The study consisted of sixty-six subjects followed for about sixteen years post-treatment. The mandibular anterior teeth had been retained with removable or bonded retainers for three years after treatment and retention was subsequently discontinued. Results showed that each subject showed increased incisor irregularity after the retainers were removed. The authors stated that although irregularity increased, it was only by an average of 1.3mm with an interquartile range of 2.35mm. Interestingly, subjects with interproximal restorations throughout the observation period had the greatest amount of mandibular incisor crowding. It was concluded that interproximal restorations could potentially lead to post-orthodontic tooth movement, but that orthodontics is not intrinsically unstable.

Other causes of relapse that are out of the control of the orthodontist include soft tissue changes and late growth changes, specifically mandibular growth. Both of these changes are part of the normal aging process. Technically, stability does exist in neither the craniofacial skeleton nor the dentition following treatment. Relapse

may be related more to the growth pattern of the individual than the dentition. The occlusion responds to changes in growth by adapting to maintain a stable intercuspation at the expense of mandibular anterior alignment. According to Melrose and Millett, crowding of the mandibular anterior dentition sometimes does not occur if the maxilla also grows forward. Mandibular incisor crowding has been found in extraction, serial extraction, and non-extraction treatments (Melrose and Millett 1998).

Sinclair and Little in 1983 and again in 1985 studied the changes during maturation of sixty-five untreated normal occlusions to determine the nature of the developmental process. The subjects had clinically acceptable occlusion with no orthodontic treatment. Results showed a decrease in total arch length and intercanine width, which may be linked to increases in mandibular incisor irregularity. Females had more severe changes than males, but males tended to grow later than females. The researchers could not determine, though, associations with or predictors of lower anterior irregularity.

Similar to Sinclair and Little, Eslambolchi and coworkers in 2008 wanted to determine the reason why mandibular incisor crowding is a continuous process. The study consisted of fifteen untreated adolescents with eighteen controls. Results indicated that arch length, intercanine width, and interpremolar widths decrease with age. This corroborated with Sinclair and Little's conclusions, stressing the importance of retention to avoid late developmental crowding. These studies of

untreated occlusions have shown that untreated individuals in a sense experience relapse.

Is post-orthodontic stability achievable or is it safe to assume that all cases with show some post-treatment tooth movement? Aasen and Espeland (2005) developed a treatment strategy aimed at maintaining mandibular anterior alignment without using retainers. This treatment included a heavy mandibular archwire in place for two to three months to establish alignment of the roots of the incisors followed by a four-week period without archwires before removing orthodontic appliances. If any incisors relapsed, interproximal reduction was completed before realignment and completion of treatment. Additionally, rotated teeth were overcorrected during the initial stages of treatment. The study included fifty-six patients that completed orthodontic treatment three years prior. Results showed that the irregularity of the incisors increased over the three-year period, but decreased overall from pre-treatment to three years post-treatment. The authors regarded the irregularity at three years post-treatment as satisfactory. Interproximal reduction was deemed necessary in this study to gain space for the correction of crowding and counteract for the naturally occurring decrease in the intercanine width. Even though irregularity existed at the three-year mark, the authors concluded that good stability was achieved without the use of mandibular retention.

Lyotard et al. (2010) assessed in a short-term study post-orthodontic tooth movement in the absence of retention. Thirty patients were included in the study and

final archwires were removed at the end of active treatment. The dentition was assessed four weeks later, including maxillary and mandibular crowding or spacing, overbite, overjet, and mandibular intercanine and intermolar widths. At the four-week evaluation, thirteen patients had their braces removed and seventeen required more treatment. Mandibular crowding, overjet, and interproximal contacts worsened for each individual in the sample. Interestingly, mandibular intercanine width had the least amount of change after active orthodontic treatment to four weeks later. This disagrees with results from previous studies that the mandibular intercanine width should decrease over time, but it was a short-term study versus other long-term efforts.

Ormiston and coworkers (2005) studied the importance of treatment duration, retention time, PAR score, pre-treatment incisor irregularity, and sex for long-term stability. The retrospective study included eighty-six patients that were divided into stable and unstable groups. Stability was determined using the PAR score at post-retention. It was determined that treatment duration and retention time was not significant when comparing the differences between stable and unstable groups. Male sex, including increased facial growth, was associated with increased instability. Results also indicated that subjects with more severe pre-treatment irregularity and PAR scores were less stable. The authors concluded that high quality results tended to worsen, while lesser quality results improved. This study was limited to only two groups, stable and unstable. A wider range of outcomes including more groups of subjects could have led to noteworthy conclusions.

There has been no consensus on how to avoid post-orthodontic tooth movement, even though it has been studied extensively. Studying the bone width between mandibular incisors and its possible association with post-treatment changes may shed some insight on this complex problem in orthodontics.

The choice of retainer and length of retainer wear currently in use in orthodontics are based heavily on practitioner preference, experience, and ease of use. Not much of the decision on which type of retainer to prescribe is based on science. Retainers were unheard of until the early 1800s when J.M. Alexis Schange described the need for retention. He utilized a rubber band on an appliance attached to hooks on the molars (Weinberger 1934). In 1919, Charles Hawley designed his famous retainer that remains very popular among practitioners. The idea for this retainer was obtained during time spent in Germany with Dr. R.D. McBride, who used a rubber palatal plate with heavy flat bars of metal passing between the first molars and second premolars to the buccal surface (Hawley 1919).

According to Gottlieb (1986, 1990, 1996), Hawley retainers declined in popularity during the late 1980s and early 1990s, when other methods, such as bonded canine to canine and invisible retainers, increased in use throughout the United States. The idea of invisible retainers (vacuum formed retainers, VFRs) began in the early 1970s, and were initially fabricated from black vulcanite rubber. The materials for fabrication transitioned into polyurethane, polyvinylacetate, polypropylene, and polyethylene polymers (Ponitz 1971). The most popular and

wear resistant material used currently is a polyethylene terephthalate glycol copolymer, but polypropylene-based materials are still commonly used as well (Gardner et al. 2003).

The popular Essix retainer was introduced by Sheridan and coworkers in 1993 and recommended for permanent retention instead of Hawley retainers. The "invisible" retainer was esthetically more acceptable to the patient. Sheridan recommended that the clear retainer should only be worn during the night to prevent the development of an open bite (Sheridan et al. 1993).

Orthodontists in the United States currently recommend both types of removable retainers. Valiathan and Hughes (2010) found that practitioners more commonly prescribe Hawley retainers than VFRs for the mandibular arch. In this study, 40.2% of orthodontists used bonded lingual retainers, 28.1% mandibular Hawley retainers, and 18.2% VFRs, with the remaining using spring aligners. Bibona and coworkers (2014) surveyed 894 orthodontists throughout the United States to determine how orthodontists decide the type of retainer to utilize for their patients. Half of the orthodontists surveyed determine the type of retainer to use at the end of treatment and 43% decide before treatment begins. The pretreatment malocclusion was considered most frequently when determining the type of retainer prescribed for each individual patient, followed by patient compliance and oral hygiene.

Hichens et al. (2007) performed a randomized, controlled trial and showed that the majority of patients preferred the VFR type to the Hawley retainer.

Furthermore, patients who are prescribed mandibular VFRs are significantly more likely to be very satisfied currently with the results of their orthodontic treatment than those with mandibular Hawley retainers. Patients with Hawley retainers are much less likely to be wearing them as prescribed when compared to VFRs. According to Mollov et al. (2010), there is a strong relationship between the perception of tooth stability after braces and satisfaction with the overall results.

Even if the patients are more satisfied with VFRs, are they more effective than Hawley retainers? According to Rowland et al. (2007), over a six-month period of retention, VFRs were more effective than Hawley retainers at maintaining correction of the mandibular dentition. There was a median difference of 0.56mm in the mandibular arch when comparing VFR and Hawley retainers. The authors concluded that this movement of the mandibular incisors could be clinically significant, especially if concentrated on one tooth.

Demir et al. (2012) concurred with the results of Rowland and coworkers in a study with a one-year retention period. Results showed that the relapse of the anterior dentition was clinically significant with the Hawley retainer when using Little's irregularity index as assessment. They concluded that VFRs were better at retaining the anterior mandibular teeth than Hawley retainers during a one-year retention period. However, the authors stated that all of the variables tended to return to their original values two years after removal of the orthodontic appliances.

Conversely, Barlin et al. (2011) came to a different conclusion. In this retrospective and randomized study, blinded observers compared intermolar widths, intercanine widths, arch length, and Little's irregularity index between Hawley and VFR retainers. The observers determined that there was no statistically or clinically significant difference between Hawley retainers and VFRs when assessing the aforementioned variables. They believe that other factors are more important when determining which retainer is appropriate for the patient.

A recently published systematic review evaluated the differences between VFRs and Hawley retainers. Only seven articles met the inclusion criteria for this study, which were the use of VFRs or Hawley retainers following orthodontic treatment, follow up for at least six months after treatment, and controlled clinical trials or randomized, controlled trials. Results for this review showed that there was no difference between the two types of retainers when assessing changes in intercanine and intermolar widths. Also, there was inadequate evidence to claim that VFRs are superior to Hawley retainers when comparing cost effectiveness, interproximal contacts, patient satisfaction, periodontal health, and survival time (Mai et al. 2014).

Some practitioners recommend fixed retention of the mandibular incisors to avoid post-treatment orthodontic changes. Sadowsky et al. in 1994 assessed the records of a practitioner that exclusively used fixed, long-term retention of the mandibular incisors. Although the sample size included only twenty-two patients, it

was determined that the mandibular incisors remained stable with a mean fixed retention time of eight years. The mandibular intercanine width also remained stable. Good alignment between the mandibular incisors can be maintained, but oral hygiene and periodontal health can be compromised by this approach.

Retention protocols are driven significantly by the opinion of the orthodontist. At a local meeting of orthodontists in 1919, Hawley was asked how often to wear removable retainers. He responded with "Oh, I don't know, six months full, six months part time" (Littlewood 2006). This decision at that time did not appear to be based on science, but to this day, that regimen remains one of the most common for orthodontists worldwide.

Valiathan and Hughes (2010) surveyed 658 orthodontists around the United States to determine the most common retention practices. The majority of orthodontists recommended a period of full time retainer wear followed by nighttime wear. Patients with Hawley retainers were asked to wear them full time for longer (3 to 9 months) compared with patients with VFRs (less than 3 months). Lifetime retention with removable retainers was recommended by 84.2% of orthodontists in this study. Intervals between retention appointments were also greater for VFRs than Hawley retainers.

When taking a poll of top orthodontists around the United States, opinions on VFRs and Hawley retainers differ drastically. Some claim that Hawley retainers are dependable, effective and versatile, while others state that they are very limited in

their ability to retain mandibular incisor position. The same can be said of VFRs, with some stating that they are the retainer of choice, with others discounting them for lack of durability (Graham 2013).

What about the issue of patient compliance with removable appliances? Kacer et al. (2010) showed that the majority of patients continued to wear their retainers for the first two years after completion of orthodontics. Although all of the orthodontists surveyed recommended nighttime wear of removable retainers for the first two-year period, the number of patients not wearing their retainers at all increased. At 19-24 months, 19% of the patients surveyed were not wearing the retainers. Overall compliance at this time was 45% for the patients surveyed. This study was the first and seemingly only of its kind studying patient behavior in the first few years after removal of braces.

Strong evidence on methods to avoid post-treatment changes and improve stability is greatly lacking. Littlewood et al. attempted to determine a retention strategy that could best maintain treatment results. The authors performed a systematic review of the studies available on retention and stability. The eligible studies needed to be randomized or quasi-randomized controlled trials, include children and adults who wore retainers after orthodontic treatment, and assess outcomes after a period of post-retention. After reviewing all of the relevant literature, only five studies were eligible for inclusion, and no two studies compared the same methods of retention. As a result, no determination could be made as to the

effectiveness of the different retention strategies in the studies. The authors concluded that there is inadequate data and low quality research available to base decisions on retention. Much higher quality research is desperately needed in this area before any recommendations on retention and stability could be made (Littlewood et al. 2006).

With the advent of cone beam computed tomography (CBCT) in the late 1990s, measuring the amount of bone surrounding teeth is easy, accurate, and reliable. In 2005, Huang et al. described the many benefits of CBCT for use in orthodontics. Some of these included a 1:1 representation of the patient, occlusal views of the arch form, three-dimensional views of the crown and root of the teeth and position of the root in the alveolus, and generation of imagines that are similar to conventional two-dimension films.

Periago et al. (2008) tested the reliability and accuracy of measurements made on 3-D reconstructions to direct measurements on dry skulls. The authors used twenty-three dry skulls for this study measuring fourteen landmarks and twenty linear distances. The 3-D measurements were found to be reliable with an intraclass correlation coefficient of 0.976. They determined that 90% of the measurements had an average difference of less than 2mm, and these differences could have been due to voxel size.

Further, Baumgaertel et al. (2009) assessed CBCT scans on thirty dry skulls and compared ten measurements made using these scans with measurements made

using digital calipers. The authors showed that the measurements made with both methods were reliable and recommended the use of measurements from CBCT scans for quantitative analysis. They did conclude that the CBCT data slightly underestimated the measurements when compared to digital caliper measurements. This could be due to measurement error of the software measuring the distance between midpoints of mesial and distal voxels of a tooth and not mesial and distal contours of a tooth.

Published literature on CBCT and mandibular incisors is scarce. In a master's thesis, Schilling and coworkers (2011) developed a reliable method to evaluate the root position of the mandibular incisors using CBCT pre- and post-orthodontic treatment. CBCT scans were assessed for fifty-one subjects and measurements were taken at the incisal edge and one-third the length of the root for each mandibular incisor. It was determined that the mean root movement in the sagittal plane was lingual and in the coronal plane was distal; mean crown movement in the sagittal plane was labial and in the coronal plane was distal. Rotations cannot be assessed using the displacement measurement. It was concluded that CBCT scans could be employed to measure the displacement of teeth throughout orthodontic treatment. Future studies will hopefully include a larger sample and use this method to assess types of treatment, such as extraction versus non-extraction.

Similarly, in another master's thesis, Carmen et al. (2011) assessed the bone thickness of the mandibular incisors using CBCT scans of forty patients before and

after orthodontic treatment. Measurements were taken on the labial and lingual surfaces of the incisors at the one-third and two-third root level. Results showed that the method of measurement was reliable, and thickness of bone increased on the facial surface and decreased on the lingual surface. Interestingly, there were no areas of the root without bony support after treatment, even in cases of excessive proclination following treatment. The authors reasoned that these observations are because tooth movement is osteogenic, increasing bone thickness in the direction of movement. It was concluded that this study was the first to show a reliable method for measuring bone thickness surrounding mandibular incisors.

Since measurements taken from CBCT scans have been shown to be accurate and reliable when measuring the bone surrounding mandibular incisors, the aim of this study is to determine any association between the bone width surrounding mandibular incisors and post-orthodontic tooth movements. Long-term stability is an important focus in orthodontics, as almost every orthodontist recommends long-term retention of corrected tooth alignment. Is there an association between alveolar bone width encasing mandibular incisors and post-orthodontic tooth movement?

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STATEMENT OF THESIS

The aim of this study is to determine the association between the bone width surrounding mandibular incisors and post-orthodontic tooth movements. It is hypothesized that there is no association between bone encircling mandibular incisors and post-orthodontic relapse.

Association between Alveolar Bone Width and Post-Orthodontic Tooth Movement

Authors: Lucas D. McGuire D.M.D.[1]

J. Martin Palomo D.D.S., M.S.D.[2]

Mark G. Hans D.D.S., M.S.D.[3]

Sena Narendran D.D.S., M.Sc., D.D.P.H.[4]

Manish Valiathan M.D.S., D.D.S., M.S.D.[5]

1. Resident, Department of Orthodontics, Case Western Reserve School of Dental Medicine, Cleveland, OH
2. Program Director and Associate Professor, Department of Orthodontics, Case Western Reserve University School of Dental Medicine, Cleveland, OH
3. Professor and Chairman, Department of Orthodontics, Case Western Reserve University School of Dental Medicine, Cleveland, OH
4. Associate Professor, Department of Community Dentistry, Case Western Reserve University School of Dental Medicine, Cleveland, OH; Program Director, Residency Program in Dental Public Health, Case Western Reserve University School of Dental Medicine, Cleveland, OH
5. Associate Professor, Department of Orthodontics, Case Western Reserve School of Dental Medicine, Cleveland, OH; Program Director, Fellowship in Craniofacial Orthodontics, Case Western Reserve University School of Dental Medicine, Cleveland, OH

Corresponding Author:

Manish Valiathan, M.D.S., D.D.S., M.S.D.
Case Western Reserve University
School of Dental Medicine
Department of Orthodontics
10900 Euclid Ave.
Cleveland, OH 44106

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Objective: The aim of the study was to investigate any association between bone width surrounding mandibular incisors and post-orthodontic tooth movements. **Methods**: The study sample consisted of 16 males and 30 females with an average age of 13.4 ± 1.7 years before orthodontic treatment (T_0), 15.5 ± 1.7 years after treatment (T_1), and 17.0 ± 2.3 years at least six months after treatment (T_2). Using Dolphin's imaging software interproximal, labial, and lingual bone thickness was measured on cone beam computed tomography scans. Crowding and intercanine width were measured on dental casts. **Results**: Tooth movement at T_2 was less than 1mm for 39 subjects and more than 1mm for 7 subjects. The bone width increased between T_0 to T_1 by 0.44 ± 0.47mm between the incisors, decreased 0.07 ± 0.29mm labially, and decreased 0.69 ± 0.68mm lingually. **Conclusions**: There was no association between bone width surrounding mandibular incisors and post-orthodontic changes.

INTRODUCTION

Stability and relapse of the dentition following orthodontic treatment has been an area of interest for orthodontists, particularly as it relates to mandibular incisor alignment. Little's irregularity index[1] is commonly used to measure the linear displacement of the anatomic contact points of each mandibular incisor. The sum of the five displacements represents the degree of mandibular incisor irregularity. Through his work, Little concluded that "the degree of crowding that develops after retention is variable and unpredictable[2]." Orthodontists' ability to predict post orthodontic changes for individual patients remains a challenge.

Contributing factors to stability of the dentition have been discussed for over a hundred years. Kingsley[3] determined that occlusion is critical to long-term stability. If the dentition were in the proper cusp and embrasure relationship following orthodontic treatment, it would remain stable. Rogers[4] believed that muscular balance was the key to treatment stability and advised muscular training of patients during orthodontic treatment. Lundstrom[5] placed great importance on the apical base to establish stability, and Tweed[6] and Margolis[7] extended this further to include the incisor angulation in reference to the mandibular plane. Mandibular intercanine width is another predictor of stability. Numerous studies have investigated the expansion of the intercanine width during treatment with incisor irregularity post-treatment.[8-17]

Sinclair studied the changes during maturation of untreated normal occlusions to determine the nature of the developmental process,[18,19] and found a decrease in

total arch length and intercanine width, which may be linked to increases in mandibular incisor irregularity. Sinclair, however, could not identify any association with or predictors of lower anterior irregularity. Eslambolchi et al. corroborated Sinclair's conclusions, stressing the importance of retention to avoid late developmental crowding.[20] These studies of populations without any orthodontic treatment have demonstrated that occlusal changes over time are a normal event.

Other predisposing factors associated with post-orthodontic changes include the composition and behavior of periodontal fibers,[21-23] incisor dimensions,[24] soft tissue changes, occlusion, and late mandibular growth.[25] Methods of avoiding post-treatment changes have been proposed with guarded findings, including fiberotomy, interproximal reduction of enamel, and maintenance of the pre-treatment incisor position.[26] Studies have demonstrated that clinicians' inability to predict post treatment changes has contributed, at least in part, to the increase in fixed retainer use.[27]

Studies quantifying the bone around mandibular incisors in relation to stability appear to be sparse. The aim of this study was to determine any association between the bone width surrounding mandibular incisors and post-orthodontic tooth movements. It is hypothesized that there is no association between bone surrounding mandibular incisors and post-orthodontic tooth movement.

MATERIALS AND METHODS

Institutional Review Board approval was obtained prior to the start of this observational study, which included patients recalled after the completion of treatment at a university in the Midwest. All adolescent patients treated in the graduate orthodontic department were eligible for inclusion in this study. The study sample included 46 subjects in retention for at least six months. The sample size was calculated using an effect size of 0.5mm and standard deviation of 1.64mm.[18]

Subjects presenting to the clinic for scheduled retention visits were invited to participate in the study. Following necessary consent, an impression of the mandibular arch was obtained by an investigator (LM). As an incentive, subjects were compensated for their participation, with either a free upper or lower retainer or a ten-dollar iTunes gift card.

Data from each patient included: 1) initial cone beam computed tomography scan (CBCT), 2) final CBCT after the braces were removed, 3) measurements made from initial plaster models of the teeth before the braces were placed, 4) measurements made from final models of the teeth after the braces were removed, and 5) measurements made from models of the teeth that are taken at least six months after braces. Data were also collected on certain demographic attributes. The CBCT scans were constructed using Dolphin's imaging software (Dolphin Imaging, Chatsworth, CA), and bone widths were measured around the lower incisor teeth before and after braces using millimeter ruler tools in Dolphin. The time points

included in the analysis were: T_0, which represents the state of the patient's dentition before orthodontic treatment, T_1, end of orthodontic treatment, and T_2, at least six months after orthodontic treatment.

Bone quantity was measured using the CBCT in three locations: labial, lingual, and interdental at the cementoenamel junction (CEJ), two-thirds the length of the root from the CEJ, and apex. All data were recorded and stored in Microsoft Office Excel 2007. Each CBCT was oriented according to the method described by Wu et al.[28] First, orient the subject in the coronal view so that the axial plane is aligned with the optic foramen (Figure 1). Second, orient the subject in the axial view so that the coronal plane is aligned with the left and right foramen ovale (Figure 2). Third, orient the subject in the sagittal view so the coronal plane passes through the foramen cecum. In the sagittal view, orient the subject so the axial plane overlaps McRae's line (Figure 3). Finally, the orientation was saved with the axial plane on McRae's line, sagittal plane on foramen cecum, and coronal plane on basion (Figure 3).

Bone surrounding the mandibular incisors was measured according to the method described by Carmen et al.[29] In the axial view, align the sagittal slice so that it locates the mandibular incisor to be measured. In the sagittal view, align the axial slice so that it is located at the CEJ, two-thirds root length from the CEJ to apex, or apex. In the axial view, use the 2-D line measurement tool in Dolphin to measure the interdental bone from mesial of one incisor to distal of the next (Figure 4). In the

axial view, use the 2-D line measurement tool in Dolphin to measure the labial bone from the labial surface of the alveolus to the labial surface of the root (Figure 5). In the axial view, use the 2-D line measurement tool in Dolphin to measure the lingual bone from the lingual surface of the alveolus to the lingual surface of the root (Figure 5).

Dental casts measured the amount of crowding before and after treatment, as well as six months after debond, using a digital caliper. Displaced mandibular incisors from the ideal arch perimeter determined the amount of crowding. One millimeter of crowding between the mandibular canines was deemed unacceptable at T_2. Intercanine widths were also measured from the dental casts and CBCT scans at the cusp tip, CEJ, two-thirds root length, and apex. A total of 78 measurements were recorded for each subject.

Mean differences in the amount of bone before and after orthodontic treatment were calculated resulting in three such scores: mean difference in interdental bone, labial bone, and lingual bone. As the measurements made of bone width at the CEJ were extremely small, they were excluded from analysis. Positive measurements indicated more bone, and negative measurements indicated less. The data were analyzed using Statistical Package for the Social Sciences (SPSS 21.0, Inc. Chicago, IL). Pearson's correlation coefficients evaluated potential associations between the tooth size to arch length discrepancy at T_2 and the mean interdental, labial, and lingual bone change, with a significance level of 0.05. Reliability was measured by

repeating full measurements after a two-week period in ten randomly selected subjects using a random number generator. The intraclass correlation coefficient was calculated using SPSS. The intraclass correlation was 0.95.

RESULTS

The study sample consisted of 46 subjects, 30 of which were female and 16 male. The mean age at T_0 was 13.4 ± 1.7 years, at T_1 was 15.5 ± 1.7 years, and at T_2 was 17.0 ± 2.3 years. The overall mean change of interdental bone before and after orthodontic treatment was 0.44 ± 0.47mm, for labial bone was -0.07 ± 0.29mm and lingual bone change was -0.69 ± 0.68mm. Tooth movement at T_2 was less than 1mm for 39 subjects and more than 1mm for 7 subjects. The mean amount of post-orthodontic tooth movement at T_2 was -0.38mm ± 0.83mm, with a range of 3mm of spacing to 3.1mm of irregularity.

The strengths of the association between post-orthodontic tooth movement at T_2 and amount of bone surrounding mandibular incisors were: r = -0.077, 0.168, and -0.132 between relapse and interdental, labial, and lingual bone, respectively (p = 0.609 for interdental bone, 0.265 for labial bone, and 0.382 for lingual bone). None of these associations were statistically significant.

DISCUSSION

The aim of this study was to understand the changes in the amount of bone before and after orthodontic treatment when considering post-treatment relapse. Although no association was found between bone around mandibular incisors and changes during the retention phase, the modest findings contribute to better understanding predictors of post orthodontic changes.

Overall, the bone measurements were considered small, especially changes in labial bone. The amount of bone surrounding mandibular incisors did not demonstrate specific patterns or associations with post-orthodontic changes. Bone measured labially, lingually, and interdentally after orthodontic treatment was variable for each subject and appeared to have little effect on the stability of treatment at least six months after the appliances were removed. The study failed to reject the null hypothesis that there is no association between bone surrounding mandibular incisors and post-orthodontic tooth movement.

In the current study, the low level of association between bone quantity and tooth movement after treatment could be due to a number of factors. The quantity of bone at the time the braces were removed (T_1) may not be as great as after a longer period of stabilization with retention. Although a CBCT was not taken at T_2, the quantity of bone measured at T_2 might challenge the current findings. Furthermore, an increase in interdental bone was not associated with post-orthodontic tooth

stability or movement. Clinically this may imply that root parallelism, a standard in finishing orthodontic cases, may not be a predictor of long-term stability.

The effects of the periodontium on post-orthodontic changes[21-22], as argued by several distinguished researchers, might be more important than the bone supporting the mandibular incisors with regards to post-treatment movement. Though supracrestal fibers may not have a substantial role in post-orthodontic changes[30], elastic fibers in the gingival tissues may require further investigation[23]. Adjunctive periodontal procedures that target the elastic fibers in conjunction with orthodontic treatment may contribute to establishing long-term stability.

The etiologies of post-orthodontic changes are multifactorial and therefore difficult to investigate. Among the multiple factors to be considered in studying this critical area of the orthodontic specialty, our ability to recall patients, patient compliance, bone quantity, periodontal status, types of treatments/appliances and duration of care to mention a few, limit our ability to arrive at valid conclusions. Further studies to determine the nature of this multifactorial concern are urgently needed.

CONCLUSIONS

1. There is no association between the amount of labial, lingual and interdental bone change surrounding mandibular incisors and post-orthodontic tooth movement.
2. The periodontium may have a stronger role that bone thickness in long term stability.
3. Root parallelism does not appear to be a predictor of long term stability.
4. Post-orthodontic changes are multifactorial.
5. Further research is essential to better understand the etiology of post-orthodontic tooth movement.

FIGURES

Figure 1: Orientation of the axial plane with optical foramina parallel in the coronal view

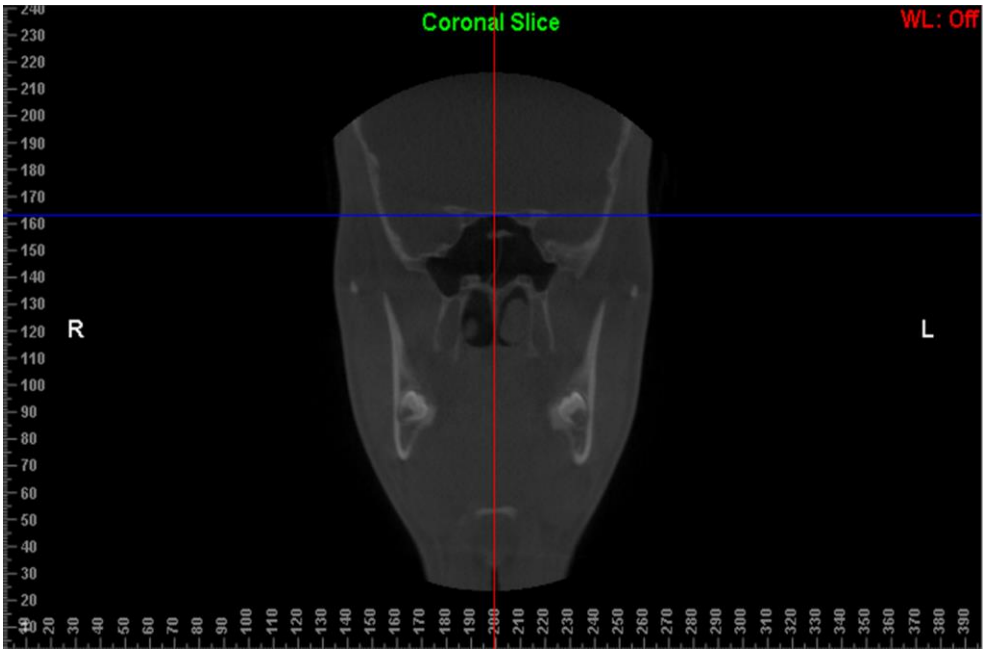


Figure 2: Orientation of the coronal plane with foramina ovale in the axial view

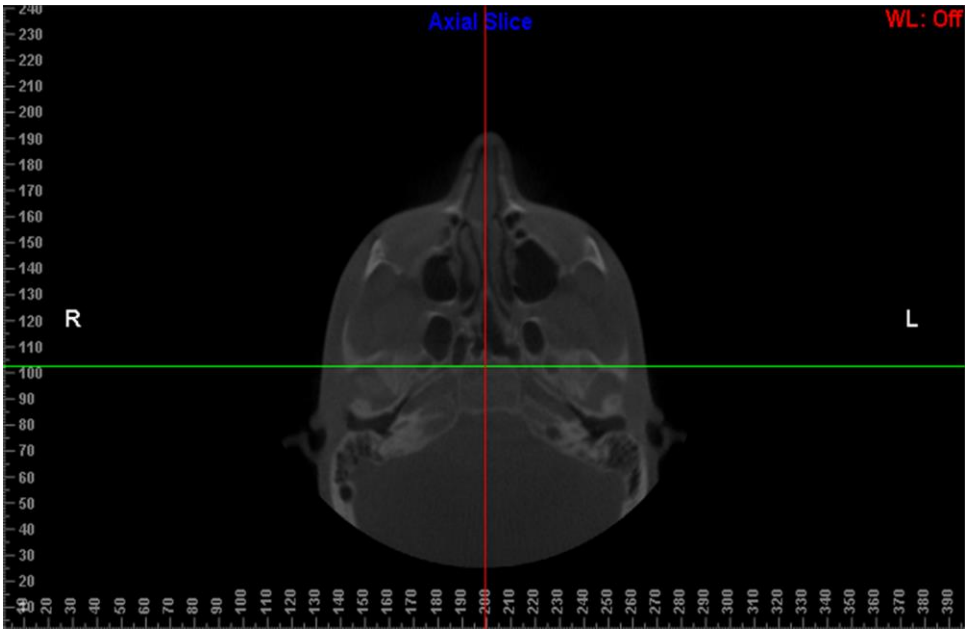


Figure 3: Orientation of the axial plane with McRae's line in the sagittal view; saved orientation where all three planes intersect at basion

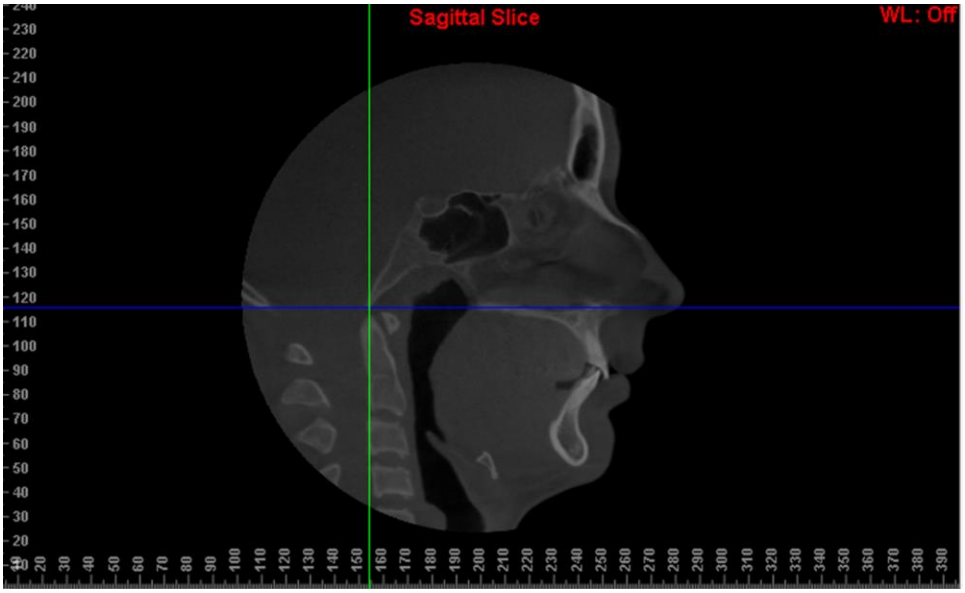


Figure 4: Interdental measurement at the level of the apex between the LR2 and LR1

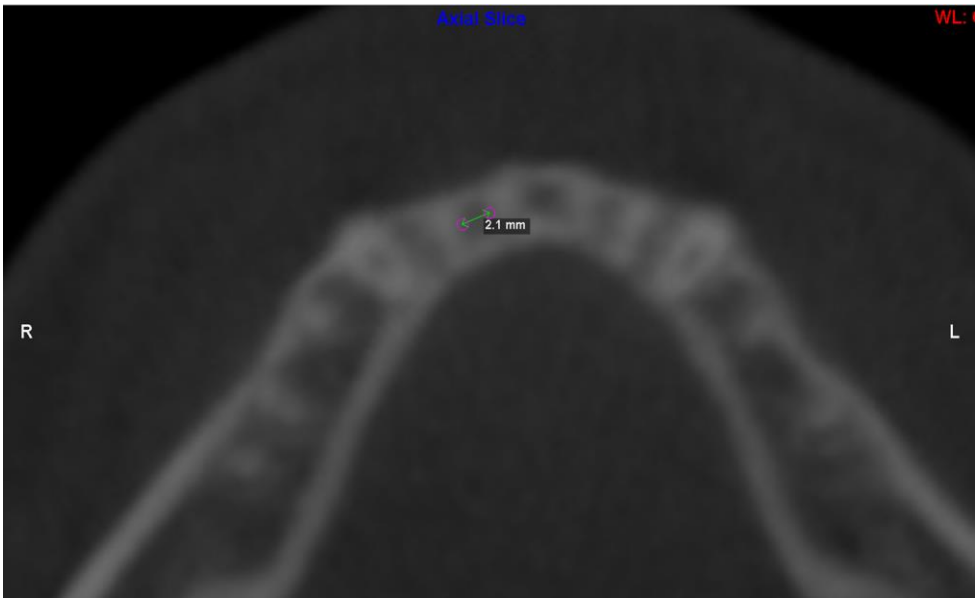
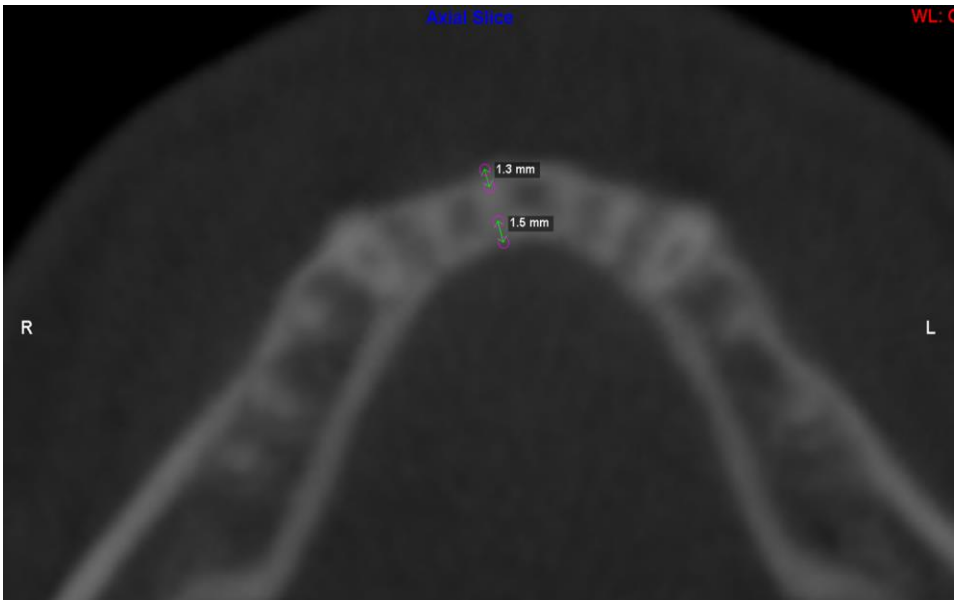


Figure 5: Labial and lingual measurements of LR1 at the level of the apex



TABLE

Table I: Mean Interdental, Labial, Lingual Differences and Tooth Size Arch Length Deficiency (TSALD) at T_2 (millimeters)

Subjects	TSALD	Mean Interdental Bone	SD	Mean Labial Bone	SD	Mean Lingual Bone	SD
WA240	-0.3	1.03	0.64	0.09	0.26	-0.65	0.75
BA281	-1.3	0.75	0.61	0.04	0.30	0.35	1.23
BR332	-0.2	0.25	0.20	0.19	0.14	-0.51	0.69
GR221	-0.4	-0.23	0.59	0.30	0.30	-0.26	0.64
MA419	3	0.00	0.21	-0.14	0.53	-0.86	0.40
WA225	-0.1	0.45	0.51	-0.24	0.64	-1.06	1.04
KE113	-0.3	-0.03	0.21	-0.03	0.48	-0.45	0.38
TE49	0	0.92	0.56	-0.04	0.26	-0.56	0.71
BR317	0.4	0.03	0.36	0.46	0.51	-2.21	0.81
BA250	-0.3	1.12	0.47	-0.08	0.24	-0.61	0.42
MO234	-0.2	-0.68	0.40	0.19	0.37	-1.23	0.87
GR186	-1.5	0.05	0.22	-0.04	0.52	-0.88	0.55
KA150	-0.5	0.47	0.63	-0.39	0.36	-1.31	0.74
WI242	-3.1	0.22	0.35	-0.96	0.62	0.06	0.55
PE179	-0.7	0.27	0.32	-0.55	0.28	-0.93	0.61
KN26	-1.3	0.10	0.41	-0.08	0.32	0.01	0.44
HE120	0.4	0.43	0.48	-0.41	0.46	-0.81	0.89
ZD5	0.4	0.53	0.42	0.40	0.37	-0.71	0.38
FE46	0.2	1.18	0.84	-0.11	0.24	0.11	0.58
CO276	-0.8	0.27	0.24	0.21	0.24	0.16	0.30
GR224	-1.3	0.57	0.41	0.03	0.37	-0.13	0.54
BR247	-0.5	1.77	1.29	-0.55	0.99	-0.43	0.62
KE105	-0.5	0.60	0.40	0.19	0.27	-0.33	0.41
MA416	-0.8	-0.08	0.28	0.14	0.24	-0.63	0.39
KO136	-0.2	0.63	0.31	0.04	0.30	-0.79	0.71
VI32	-0.4	0.78	0.45	0.09	0.33	-1.03	1.14
SO19	0	0.07	0.43	-0.24	0.37	0.10	0.40
OW18	-0.2	0.67	0.45	-0.16	0.31	-1.58	1.04
CA258	-1.2	0.40	0.63	0.13	0.27	-3.13	0.84
TH109	-0.3	0.28	0.37	-0.34	0.31	-0.96	0.51
SA176	0	0.43	0.15	-0.25	0.25	-0.36	0.38
KA124	0	0.18	1.00	-0.30	0.31	-0.56	0.16
OK6	-1	1.30	0.81	-0.44	0.74	-1.71	0.72
OG5	0	0.68	0.54	-0.08	0.44	-0.70	0.28
RO182	-0.3	0.55	0.93	0.18	0.46	-0.41	0.67

SA160	-0.1	0.50	0.96	-0.31	0.25	-0.45	0.72
TA135	0	0.38	0.50	-0.44	0.60	-1.75	0.74
HA142	-0.4	-0.23	0.21	-0.15	0.34	-0.08	0.27
GA161	-0.7	0.05	0.15	0.63	0.31	-1.49	0.66
GA164	-2.1	0.73	0.65	-0.04	0.14	-0.23	0.25
ST238	0	0.08	0.48	-0.24	0.12	-0.48	0.42
PA212	0	0.30	0.41	0.18	0.21	-1.33	0.89
HU148	-0.5	0.62	0.34	0.28	0.23	-0.69	0.52
FE60	-0.1	0.05	0.20	-0.08	0.33	-0.59	0.51
PR96	0	0.42	0.44	-0.21	0.42	0.63	0.41
SU68	-0.3	1.50	0.51	0.01	0.41	-0.54	0.27
Average	-0.38	-0.08	0.48	0.17	0.36	-0.13	0.60

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Appendix A: IRB Approval

CASE WESTERN RESERVE UNIVERSITY EST. 1826

NOTICE OF APPROVAL

CWRU IRB Protocol Number:	**IRB-2013-538**
Protocol Title:	***Alveolar Bone Width and Post-Orthodontic Tooth Movement (Crowding): Is There an Association?***
Responsible Investigator (RI):	**Manish Valiathan**
Co-Investigator (CI):	**Lucas McGuire**
RI Department:	**Orthodontics**
Type of Review:	**Expedited**
Risk Level:	**Minimal**
Vulnerable Population(s):	**Children**
Approval Date:	**09/18/2013**
CONTINUING REVIEW DEADLINE:	**09/03/2014**
EXPIRATION DATE:	**09/17/2014**

The CWRU Institutional Review Board (IRB) has approved the above new protocol through the **EXPEDITED** review process.

When conducting Human Subjects' Research, your responsibilities include the following:

1. Report all adverse events and unanticipated problems involving human subjects to the IRB Office, located in the Office of Research Administration (ORA), within three (3) business days of your knowledge of the occurrence.
2. Provide the IRB with a complete Continuing Review form (available in our electronic application system at http://sberirb-app.case.edu, or from the ORA) by the continuing review deadline noted above, and when the study is to be terminated.
3. Submit all proposed changes to the protocol to the IRB and wait for IRB approval before implementing any protocol change or modification.
4. Keep all research data and original consent documents in your possession for at least three (3) years after the study is terminated.
5. Note that completely de-identified data can be kept and used for research indefinitely. The IRB is primarily concerned about identifiers/identifiable data. If you want to terminate your study, identifiers/identifiable data must be destroyed. This includes paper or electronic master lists, contact lists, codes/codebooks, transcripts containing identifiers and video and audio recordings.
6. If applicable, please use the most current IRB-approved consent forms. Feel free to use copies of these forms as long as they are identical to what was originally IRB approved. If you wish to change the forms or any other part of the study, you must submit an addendum request/protocol modification with revised copy(ies) of the relevant document(s) and wait for IRB approval before a modification can be implemented.
7. ***Discontinue all work pertaining to this protocol if a continuing review approval is NOT finalized by the expiration date noted above.*** No further work on this protocol is allowable until the proper continuing review materials or required revisions are approved by the IRB.

    a. Please note that, if the continuing review materials or required revisions are not received by the expiration date, the RI and this study would be automatically placed on Administrative Hold for 30 days. This means that the RI loses their IRB privileges and research from this study must cease.
    b. If after 30 days, the CWRU IRB still does not have the protocol for processing, this protocol will be administratively terminated and your IRB privileges will be revoked for all your protocols.

Thank you for your attention to this matter. Please contact the IRB office at 216-368-6993 if we can be of further assistance.

Adult Consent Form

Version 09/2013

INFORMED CONSENT DOCUMENT

Estimating the Association between Alveolar Bone Width and Post-Orthodontic Tooth Movement

You are being asked to participate in a research study about tooth movement after braces are removed. You were selected as a possible participant because you were treated at the CWRU Department of Orthodontics. Please read this form and ask any questions that you may have before agreeing to be in the research.

Researchers at Case Western Reserve University are conducting this study.

Background Information

The purpose of this research is to determine if there is an association between the final position of the bottom teeth and movement after braces are removed. The entire study duration will last for one year, but your participation will only be necessary once for 35-45 minutes.

Procedures

If you agree to be a participant in this research, we would ask you to do the following things:

1. Answer a few questions about the retainers that you were given when the braces were removed.
2. Make an appointment at CWRU Orthodontics to have molds of your teeth taken by an orthodontic resident.
3. The survey will only take five minutes, and the appointment for the molds of your teeth will only take roughly 30 minutes (total time will be 35-45 minutes).

Risks and Benefits to Being in the Study

This research has the following risks: There are no foreseeable risks associated with this research project.

The benefits of participation: There are no foreseeable benefits associated with this research project.

Compensation

You will receive your choice of:

1. One upper or lower retainer free of charge (valued at $50).
2. $10 iTunes gift card.

There are no costs to participating, but you will not receive any compensation if you decide not to participate in the study.

Confidentiality

The records of this research will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify a participant. Research records will be kept in a locked file, and access will be limited to the researchers, the University review board responsible for protecting human participants, and regulatory agencies.

Voluntary Nature of the Study

Your participation is voluntary. If you choose not to participate, it will not affect your current or future relations with the University or the Dental Clinic. There is no penalty or loss of benefits for not participating or for discontinuing your participation. Participating or not will not adversely affect your dental care or relations with the Dental Clinic.

You will be provided with any significant new findings that develop during the course of the research that may make you decide that you want to stop participating.

Contacts and Questions

The researchers conducting this study are Dr. Manish Valiathan and Dr. Lucas McGuire. You may ask any questions you have now. If you have any additional questions, concerns or complaints about the study, you may contact them at (216) 368-8876 or LDM54@case.edu.

If the researchers cannot be reached, or if you would like to talk to someone other than the researcher(s) about; (1) questions, concerns or complaints regarding this study, (2) research participant rights, (3) research-related injuries, or (4) other human subjects issues, please contact Case Western Reserve University's Institutional Review Board at (216) 368-6925 or write: Case Western Reserve University; Institutional Review Board; 10900 Euclid Ave.; Cleveland, OH 44106-7230.

You will be given a copy of this form for your records.

Statement of Consent

I have read the above information. I have received answers to the questions I have asked. I consent to participate in this research. I am at least 18 years of age.

Print Name of Participant: _____

Signature of Participant: _____ Date: _____

Signature of Person Obtaining Consent: _____ Date: _____

Child Assent Form

Version 09/2013

CHILD ASSENT DOCUMENT

Estimating the Association between Alveolar Bone Width and Post-Orthodontic Tooth Movement

You are being asked to participate in a research study about tooth movement after braces are removed. You were selected as a possible participant because you were treated at the CWRU Department of Orthodontics. Please read this form and ask any questions that you may have before agreeing to be in the research.

Researchers at Case Western Reserve University are conducting this study.

Background Information

The purpose of this research is to determine if there is an association between the final position of the bottom teeth and movement after braces are removed. The entire study duration will last for one year, but your participation will only be necessary once for 35-45 minutes.

Procedures

If you agree to be a participant in this research, we would ask you to do the following things:

1. Answer a few questions about the retainers that you were given when the braces were removed.
2. Make an appointment at CWRU Orthodontics to have molds of your teeth taken by an orthodontic resident.
3. The survey will only take five minutes, and the appointment for the molds of your teeth will only take roughly 30 minutes (total time will be 35-45 minutes).

Risks and Benefits to Being in the Study

This research has the following risks: There are no foreseeable risks associated with this research project.

The benefits of participation: There are no foreseeable benefits associated with this research project.

Compensation

You will receive your choice of:

1. One upper or lower retainer free of charge (valued at $50).
2. $10 iTunes gift card.

There are no costs to participating, but you will not receive any compensation if you decide not to participate in the study.

Confidentiality

The records of this research will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify a participant. Research records will be kept in a locked file, and access will be limited to the researchers, the University review board responsible for protecting human participants, and regulatory agencies.

Voluntary Nature of the Study

Your participation is voluntary. If you choose not to participate, it will not affect your current or future relations with the University or the Dental Clinic. There is no penalty or loss of benefits for not participating or for discontinuing your participation. Participating or not will not adversely affect your dental care or relations with the Dental Clinic.

You will be provided with any significant new findings that develop during the course of the research that may make you decide that you want to stop participating.

Contacts and Questions

The researchers conducting this study are Dr. Manish Valiathan and Dr. Lucas McGuire. You may ask any questions you have now. If you have any additional questions, concerns or complaints about the study, you may contact them at (216) 368-8876 or LDM54@case.edu.

If the researchers cannot be reached, or if you would like to talk to someone other than the researcher(s) about; (1) questions, concerns or complaints regarding this study, (2) research participant rights, (3) research-related injuries, or (4) other human subjects issues, please contact Case Western Reserve University's Institutional Review Board at (216) 368-6925 or write: Case Western Reserve University; Institutional Review Board; 10900 Euclid Ave.; Cleveland, OH 44106-7230.

You will be given a copy of this form for your records.

Statement of Assent

I have read the above information. I have received answers to the questions I have asked. I assent to participate in this research. I am under 18 years of age.

Print Name of Participant: _____

Signature of Participant: _____ Date: _____

Signature of Person Obtaining Assent: _____ Date: _____

Parental Consent Form

Version 09/2013

PARENTAL PERMISSION DOCUMENT

Estimating the Association between Alveolar Bone Width and Post-Orthodontic Tooth Movement

Your child is being asked to participate in a research study about tooth movement after braces are removed. Your child was selected as a possible participant because he or she was treated at the CWRU Department of Orthodontics. Please read this form and ask any questions that you or your child may have before agreeing to be in the research.

Researchers at Case Western Reserve University are conducting this study.

Background Information

The purpose of this research is to determine if there is an association between the final position of the bottom teeth and movement after braces are removed. The entire study duration will last for one year, but your child's participation will only be necessary once for 35-45 minutes.

Procedures

If you agree for your child to be a participant in this research, we would ask your child to do the following things:

4. Answer a few questions about the retainers that your child was given when the braces were removed.
5. Make an appointment at CWRU Orthodontics to have molds of your child's teeth taken by an orthodontic resident.
6. The survey will only take five minutes, and the appointment for the molds of your child's teeth will only take roughly 30 minutes (total time will be 35-45 minutes).

Risks and Benefits to Being in the Study

This research has the following risks: There are no foreseeable risks associated with this research project.

The benefits of participation: There are no foreseeable benefits associated with this research project.

Compensation

You will receive your choice of:

3. One upper or lower retainer free of charge (valued at $50).
4. $10 iTunes gift card.

There are no costs to participating, but your child will not receive any compensation if you or your child decides not to participate in the study.

Confidentiality

The records of this research will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify a participant. Research records will be kept in a locked file, and access will be limited to the researchers, the University review board responsible for protecting human participants, and regulatory agencies.

Voluntary Nature of the Study

Your child's participation is voluntary. If you or your child chooses not to participate, it will not affect current or future relations with the University or the Dental Clinic. There is no penalty or loss of benefits for not participating or for discontinuing your child's participation. Participating or not will not adversely affect your child's dental care or relations with the Dental Clinic.

You and your child will be provided with any significant new findings that develop during the course of the research that may make you decide that you want your child to stop participating.

Contacts and Questions

The researchers conducting this study are Dr. Manish Valiathan and Dr. Lucas McGuire. You may ask any questions you have now. If you have any additional questions, concerns or complaints about the study, you may contact them at (216) 368-8876 or LDM54@case.edu.

If the researchers cannot be reached, or if you would like to talk to someone other than the researcher(s) about; (1) questions, concerns or complaints regarding this study, (2) research participant rights, (3) research-related injuries, or (4) other human subjects issues, please contact Case Western Reserve University's Institutional Review Board at (216) 368-6925 or write: Case Western Reserve University; Institutional Review Board; 10900 Euclid Ave.; Cleveland, OH 44106-7230.

You will be given a copy of this form for your records.

Statement of Permission

I have read the above information. I have received answers to the questions I have asked. I permit my child to participate in this research.

Print Name of Parent or Guardian: _____

Signature of Parent or Guardian: _____ Date: _____

Signature of Person Obtaining Permission: _____ Date: _____

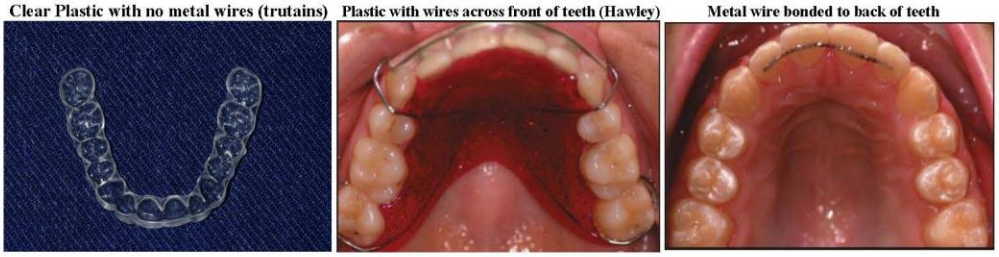
Retainer Survey

Survey Number

1) What type of retainer do you wear on your **UPPER** teeth?
(please pick retainer you wear the most often)

- ☐ Clear plastic with no metal wires (Trutain)
- ☐ Plastic with wires across front of teeth (Hawley)
- ☐ Metal wire bonded to back of teeth
- ☐ Other

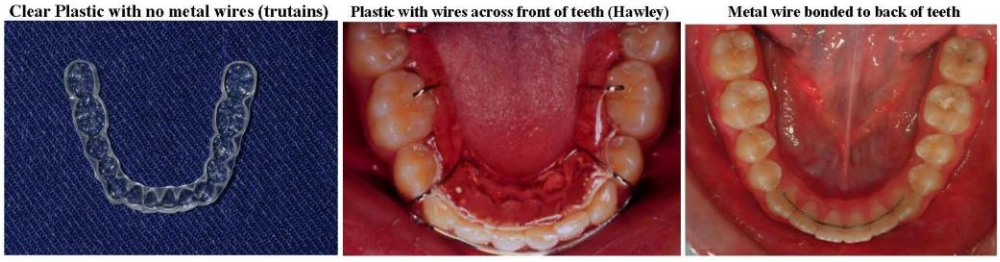
Clear Plastic with no metal wires (trutains) **Plastic with wires across front of teeth (Hawley)** **Metal wire bonded to back of teeth**



2) What type of retainer do you have for the **Lower** teeth?
(please pick retainer you wear the most often)

- ☐ Clear plastic with no metal wires (Trutain)
- ☐ Plastic with wires across front of teeth (Hawley)
- ☐ Metal wire bonded to back of teeth
- ☐ Other

Clear Plastic with no metal wires (trutains) **Plastic with wires across front of teeth (Hawley)** **Metal wire bonded to back of teeth**



3) For your retainers that are REMOVABLE, how many hours per day (including sleeping) have you been wearing them in the last few weeks?

- ☐ Have not worn retainers in the last few weeks
- ☐ Less than 9 hours per day
- ☐ 9-15 hours
- ☐ 16-24 hours

4) For your retainers that are REMOVABLE, in the last few weeks, how many nights per week have you been wearing them to bed?

- ☐ Have not worn retainers in the last few weeks
- ☐ 1 night
- ☐ 2 nights
- ☐ 3 nights
- ☐ 4 nights
- ☐ 5 nights
- ☐ 6 nights
- ☐ Every night

Appendix B: Raw Data

Subjects	Initial Age (m)	Final Age (m)	Retention Age (m)
WA240	162	187	197
BA281	149	169	179
BR332	166	186	198
GR221	157	179	193
MA419	173	194	207
WA225	146	171	183
KE113	147	170	183
TE49	166	190	202
BR317	145	169	177
BA250	150	174	181
MO234	173	195	210
GR186	180	215	231
KA150	138	163	177
WI242	158	184	220
PE179	165	190	203
KN26	174	202	213
HE120	172	187	209
ZD5	157	184	210
FE46	158	184	207
CO276	143	168	195
GR224	182	202	219
BR247	149	177	199
KE105	150	183	193
MA416	206	228	245
KO136	119	143	159
VI32	145	183	199
SO19	162	185	213
OW18	169	208	220
CA258	156	192	206
TH109	151	195	202
SA176	133	153	163
KA124	146	171	188
OK6	178	214	220
OG5	166	192	208
RO182	192	208	284
SA160	153	180	196
TA135	145	169	186
HA142	177	198	267
GA161	152	176	192
GA164	239	258	286
ST238	172	194	224
PA212	145	171	177
HU148	133	156	163
FE60	171	190	211
PR96	144	169	175
SU68	146	172	212
Average in months	160.00	185.39	203.95
Average in Years	**13.33**	**15.44**	**16.99**
ST DEV in Months	20.30	20.00	27.08
ST DEV in Years	**1.69**	**1.67**	**2.26**

Subjects	CEJ LR2-LR1 T01	CEJ LR2-LR1 T11	CEJ LR1-LL1 T02	CEJ LR1-LL1 T12	CEJ LL1-LL2 T03	CEJ LL1-LL2 T13	ROOT LR2-LR1 T04
WA240	1.1	1.4	1.4	2.2	1.7	1.5	0.7
BA281	0.8	1.8	1.2	1	1.3	1.6	1
BR332	1.3	1.5	1.4	1.5	0.8	1.2	1.2
GR221	1.2	1.2	1.4	1.2	1.2	1.5	2.1
MA419	1.9	2	1.4	1.1	1.6	1.1	1.5
WA225	1.7	2.4	1.4	1.4	1.5	1.6	2.2
KE113	0.7	1.2	1.2	1.5	1.1	1.2	1.3
TE49	1.3	0.9	1.4	1.6	1.4	1.5	1.1
BR317	1.2	1.5	1.7	1	1.8	1.4	1
BA250	0.7	1.6	1.1	1.8	0.9	1.5	0.8
MO234	0.6	0.2	1	0.4	0.8	1.1	0.9
GR186	1.1	1.1	1	1.5	1	1.1	1.4
KA150	1.3	1	0.8	1.6	0.7	1.2	0.9
WI242	0.7	0.8	0.5	0.6	0.5	0.8	0.7
PE179	1.6	1.5	1.7	1.9	1.8	2	1.4
KN26	0.5	0.9	0.8	1.3	0.8	0.9	0.7
HE120	1	1.6	1.2	0.8	1	1.5	1.3
ZD5	1.4	1	1.4	1.2	1.1	1.5	1.6
FE46	1	1.1	1.2	1.4	1.2	2.3	1.2
CO276	1.4	1.6	1.4	1.6	1	1.2	1.2
GR224	1.2	1.4	1.2	1.3	1	1.6	0.8
BR247	0.8	1.1	1.2	1.2	1.1	2.6	0.8
KE105	0.6	1.2	1	1	1	1.2	0.2
MA416	1.2	1.2	1.2	1	1.3	1.2	1.2
KO136	0.8	1.3	0.9	1.3	0.9	1.2	0.2
VI32	1	1.3	0.6	1	0.9	1.2	0.8
SO19	1	1	1.2	1.2	1	1.4	1
OW18	1.2	1.5	1.2	1.7	1	1.8	1.5
CA258	0.6	1.5	0.4	1.5	1	1.1	0.8
TH109	1.1	13	1.1	1.4	1.1	1.2	1.3
SA176	1.2	1.2	1	1.4	1	1.2	0.5
KA124	2.3	1.6	2.5	1.3	2.1	1.6	0.8
OK6	1.2	2.1	1.2	1.4	1.4	1.7	0.5
OG5	1	1.7	1	1	1.2	1.7	1
RO182	1.8	1.7	1.7	1.4	1	1.4	0.9
SA160	1.4	1.6	1.2	1.2	1.2	1.8	1.2
TA135	0.8	1.2	1.6	1.3	0.8	1.4	0.6
HA142	1.7	1.2	1.9	1.2	1.1	1.3	1.6
GA161	0.9	1	1.2	1	1	1	0.4
GA164	1	1.8	1.2	1.2	1	1.9	0.8
ST238	1.5	1	1	1.2	1.2	1.6	1.3
PA212	0.9	1.2	1.4	1.6	1.1	1.2	1.5
HU148	0.6	1	0.8	1.2	0.9	1.4	0.6
FE60	0.6	1.3	0.9	1	0.7	1	0.9
PR96	1.3	1.9	1.6	1.8	1.4	2.2	1.4
SU68	1	2	1.2	1.8	1.1	2.5	1.1

Subjects	ROOT LR2-LR1 T14	ROOT LR1-LL1 T05	ROOT LR1-LL1 T15	ROOT LL1-LL2 T06	ROOT LL1-LL2 T16	Apex LR2-LR1 T07	Apex LR2-LR1 T17	Apex LR1-LL1 T08
WA240	2.2	1.5	3	0.9	1.6	1.5	1.9	1.5
BA281	1.4	1.4	1.1	1	2	1.4	2.5	1.5
BR332	1.8	1.6	1.7	1.4	1.7	1.5	1.6	2.1
GR221	1.2	1.6	1.7	1.4	1.8	1.7	1.9	3.5
MA419	1.4	1.2	1.1	1.2	0.9	1.5	1.8	1.4
WA225	3.3	1.3	1.6	1.4	2.1	2.9	3.2	2.4
KE113	1.4	1.4	1.7	1.1	1.4	1.7	1.5	2.1
TE49	1.4	1.4	1.9	1.2	1.9	1.2	2.7	1.6
BR317	1.6	1.7	1.4	1.3	1.2	1.2	1.5	1.9
BA250	1.9	1.5	2.1	0.9	1.9	1.1	2.8	2.4
MO234	0.6	1.4	0.6	0.4	1.4	0.7	0.6	1.8
GR186	1.4	1.2	1.6	1.2	1.2	1.5	1.7	1.6
KA150	0.9	0.6	2.2	0.6	1.2	1	1	1.2
WI242	0.8	0.5	0.6	0.5	0.4	0.7	0.9	0.5
PE179	1.9	2.1	1.9	2	2.2	2.2	2.8	3.3
KN26	0.9	1	1.1	0.8	1.1	0.7	0.9	1.7
HE120	1.7	1	1	0.6	1.9	1.2	1.6	1.2
ZD5	1.9	1.4	1.6	1.4	2.3	1.7	2.5	1.6
FE46	1.8	1.4	1.6	1	2.6	1.3	2	1.4
CO276	1.6	1.6	1.6	0.6	1	1.3	1.5	1.2
GR224	1.2	0.9	0.9	1	1.4	0.8	1.4	0.8
BR247	1.9	1.4	2.1	0.8	3.3	1	2.6	1
KE105	1	0.8	1.2	0.8	1	0.2	1.4	1.2
MA416	1.4	1.5	1.2	1.2	1.3	2	2.2	1.7
KO136	1.3	0.9	1.1	0.6	1.3	0.2	0.8	0.6
VI32	1.3	0.6	1.2	0.4	1.2	0.5	1.7	0.6
SO19	1	1.6	1	1	1.2	1	1.4	2.3
OW18	1.7	1.6	1.9	1.6	2	1.7	2.4	1.4
CA258	0.6	0.6	1.6	1.2	1	1	0.9	1.4
TH109	1.3	1.1	1.2	0.6	1.3	1.6	1.7	1.8
SA176	0.9	1	1.2	0.8	1.2	0.6	1.2	0.8
KA124	1.4	2.7	1.6	1.2	2.1	0.9	1.8	2.9
OK6	1.9	0.9	1	0.7	1.4	0.5	2.9	0.7
OG5	1.9	1.6	1.6	1.2	1.8	1.8	2.7	2.2
RO182	1.8	2.8	2.4	0.6	2.1	0.6	1.8	3.7
SA160	1.7	1	0.8	1	2.1	1.8	2.1	1.9
TA135	1.2	1.6	1.1	1.2	1.6	1.1	1.6	1.2
HA142	1.4	1.4	1.4	1.7	1.6	1.7	1.4	1.8
GA161	0.6	0.6	0.4	0.4	0.6	0.6	0.6	1
GA164	1.6	0.6	0.6	0.8	1.7	1.2	2.2	0.8
ST238	1	1.2	1.6	1	1.4	2.1	1.4	1.2
PA212	1.4	1.6	1.4	1.5	1.6	2.3	2.9	1.2
HU148	1	0.8	1	0.8	1.2	0.7	1.4	0.8
FE60	1.2	1.1	1	0.9	0.8	0.6	0.6	1.1
PR96	1.3	1.6	1.8	1.2	1.4	1.2	1.5	2.5
SU68	2.4	1	1.9	1.4	2.9	1.4	3.6	1.4

Subjects	Apex LR1-LL1 T18	Apex LL1-LL2 T09	Apex LL1-LL2 T19	Labial Bone CEJ LR2 T010	Labial Bone CEJ LR2 T110	Labial Bone CEJ LR1 T011	Labial Bone CEJ LR1 T111	Labial Bone CEJ LL1 T012
WA240	3.3	1.9	2.2	0.5	0.5	0.4	0.5	0.4
BA281	2.4	1.6	3	0.7	0.3	0.5	0.2	0.7
BR332	2.2	1.6	1.9	0.6	0.3	0.5	0.3	0.6
GR221	2.5	2.1	1.9	0.7	0.2	0.5	0.3	0.5
MA419	1.5	1.4	1.5	0.7	0.5	0.5	0.3	0.5
WA225	2	2.6	3.3	0.4	0.6	0.4	0.7	0.6
KE113	1.9	1.9	1.7	0.6	0.5	0.9	0.5	0.5
TE49	2.4	1.2	2.9	0.4	0.5	0.5	0.5	0.8
BR317	1.6	1.4	1.4	1.4	1	1.1	1.2	1.2
BA250	4.1	0.9	1.8	0.6	0.6	0.7	0.6	0.7
MO234	1	0.6	1.7	0.9	0.6	0.6	0.6	0.8
GR186	1.5	1.4	1.2	1	1.1	0.8	0.8	0.8
KA150	1.8	0.8	0.8	1	1	0.7	0.8	0.8
WI242	1.4	0.7	0.8	0.8	0.6	0.9	0.6	0.9
PE179	3.3	2.6	3.1	1	0.6	0.8	0.8	0.8
KN26	1	0.6	1.1	0.8	0.7	0.8	0.3	0.9
HE120	1.2	1	1.5	0.4	0.4	0.6	0.4	0.6
ZD5	1.6	1.7	2.7	0.6	1.1	0.6	0.8	1
FE46	2.9	1	3.5	0.9	0.6	0.6	0.6	0.8
CO276	1.2	0.6	1.2	0.6	0.6	1	0.6	1.1
GR224	2	0.4	1.2	0.6	0.7	0.8	0.9	0.6
BR247	1.7	1.3	5.3	0.7	0.9	0.8	0.8	0.7
KE105	1.4	0.8	1.6	1	0.8	0.8	1	0.6
MA416	1.4	1.8	1.4	0.4	0.9	1.2	0.9	0.4
KO136	1.4	0.4	0.8	0.8	0.4	0.8	0.7	0.9
VI32	0.8	0.2	1.6	0.7	0.2	0.4	0.6	1
SO19	2.1	0.9	1.5	0.7	0.9	0.4	0.8	0.6
OW18	2.5	1.4	2.7	1	0.9	0.6	0.6	0.5
CA258	2.5	0.4	1.2	0.6	0.5	1.6	0.5	0.4
TH109	1.8	1.1	1.9	1	1	0.9	0.9	0.9
SA176	1.2	0.6	1.2	0.9	0.7	0.8	0.8	0.8
KA124	1.8	1.1	2	0.9	0.9	1	0.8	1
OK6	2.1	1	2.8	0.7	0.7	0.9	0.8	0.9
OG5	2.4	1.5	3	0.6	0.6	0.4	0.8	0.6
RO182	2.9	0.6	1.5	0.9	1.1	0.6	1	0.6
SA160	1.2	1.4	3.4	1.2	1.1	0.8	0.6	1
TA135	1.5	0.8	1.8	0.2	0.3	0.6	0.6	0.8
HA142	1.2	1.6	1.4	0.9	0.8	0.8	0.8	0.8
GA161	1	0.9	1	0.4	0.5	0.6	0.6	0.6
GA164	0.8	0.8	2.5	0.5	0.7	0.4	0.6	0.6
ST238	1.4	0.7	1.2	0.7	0.8	0.6	0.6	0.4
PA212	1.9	1	1.7	0.8	0.8	0.6	0.8	0.6
HU148	1.7	0.6	1.7	0.9	1.2	0.8	1	0.8
FE60	1	0.6	0.9	0.8	0.4	0.9	0.6	0.9
PR96	3.5	1	1.9	0.8	0.9	0.8	1	0.6
SU68	2.5	1.9	3.9	0.8	0.9	1	0.6	0.8

Subjects	Labial Bone CEJ LL1 T112	Labial Bone CEJ LL2 T013	Labial Bone CEJ LL2 T113	Lingual Bone CEJ LR2 T014	Lingual Bone CEJ LR2 T114	Lingual Bone CEJ LR1 T015	Lingual Bone CEJ LR1 T115	Lingual Bone CEJ LL1 T016
WA240	0.3	0.6	0.5	1.5	0.9	1.4	0.8	3
BA281	0.2	0.7	0.3	1	0.7	1.3	1.2	1.2
BR332	0.5	0.6	0.5	0.8	1.6	0.8	1	0.6
GR221	0.2	1	0.5	0.8	0.7	0.7	0.5	0.7
MA419	0.4	0.8	0.5	1.2	0.9	1.2	0.9	1.9
WA225	0.5	0.6	1	1.2	1.3	0.8	1.1	0.8
KE113	0.5	0.5	0.7	1.3	1.7	0.7	0.9	1
TE49	0.6	1	0.7	1	0.4	1.4	0.8	1.2
BR317	0.8	0.9	1	4.2	3.1	4.3	3.5	4.4
BA250	0.6	0.6	0.7	1	0.8	1.1	0.8	0.8
MO234	0.8	0.6	0.7	1.2	1	2	1.2	1.2
GR186	1	1	0.8	1	1	1	1	1.2
KA150	0.6	1.5	0.6	1.1	1	2.1	1.4	2.5
WI242	0.6	0.9	0.6	0.8	1.5	0.9	1.2	1
PE179	0.8	0.9	0.9	1.4	1	1.4	0.8	1.3
KN26	0.8	1	0.8	0.7	0.8	0.8	0.9	1
HE120	0.2	0.4	0.5	0.7	0.7	0.7	0.6	0.7
ZD5	0.8	0.6	0.8	0.6	0.8	0.8	0.6	0.9
FE46	0.6	0.8	0.7	1	1	0.8	1	0.8
CO276	0.8	0.8	0.9	1.5	1.4	1.4	1.4	1.4
GR224	0.4	0.4	1	3.2	2.3	2.3	1.7	1.4
BR247	1	0.7	0.8	0.9	0.9	1	0.6	1
KE105	1	0.9	0.9	0.8	1.5	1	1.2	1
MA416	0.8	0.6	0.7	1.5	0.9	0.6	1	0.8
KO136	0.6	0.6	0.7	1	0.9	0.9	0.8	0.6
VI32	0.5	0.5	0.3	0.7	1.8	1.2	1.4	0.8
SO19	0.6	0.5	0.6	1	1.9	1.2	1.8	0.8
OW18	0.6	0.9	0.7	0.5	0.9	0.6	0.8	0.6
CA258	0.6	0.8	0.6	2.2	0.8	0.6	0.9	1.7
TH109	1	0.7	0.9	1.1	1.3	1.3	1.2	0.9
SA176	0.8	1	0.9	1.9	1.6	1.9	1.8	2.4
KA124	0.8	1.2	0.9	1.2	1.2	1	1.4	1
OK6	0.8	0.5	0.6	1.3	1	1.1	1	0.9
OG5	0.6	0.4	0.7	1.1	1.1	1.4	1	1.2
RO182	0.8	0.8	1.1	1.3	1	1.1	1	1.1
SA160	0.6	0.8	1	1.4	0.9	1.7	1	1.4
TA135	0.9	1	0.7	1.3	1.1	1.6	1.1	1
HA142	0.7	0.7	0.8	1.2	0.9	1.4	0.8	1.2
GA161	0.8	0.6	0.7	3.6	2.7	4.3	3.3	3.7
GA164	0.6	0.9	0.8	1.9	1.9	1.6	1.5	1.6
ST238	0.8	0.7	0.6	1.3	1.1	1.6	1	2.1
PA212	0.8	0.7	0.8	1.1	1	1	1.2	1.2
HU148	0.9	0.6	0.7	6.7	5.6	5.5	4.5	5.7
FE60	0.6	1.1	0.4	1.7	1.7	1.8	1.9	1.7
PR96	0.6	1	0.8	2	1.6	2.1	1.4	2.3
SU68	0.7	1	0.9	1.4	1	1.4	1.2	1.2

Subjects	Lingual Bone CEJ LL1 T116	Lingual Bone CEJ LL2 T017	Lingual Bone CEJ LL2 T117	Labial Bone Root LR2 T018	Labial Bone Root LR2 T118	Labial Bone Root LR1 T019	Labial Bone Root LR1 T119	Labial Bone Root LL1 T020
WA240	1.2	1.5	0.9	0.6	1.1	0.6	0.8	0.4
BA281	0.5	1.4	0.9	1	1.2	0.5	0.8	0.9
BR332	0.8	0.9	1	1.2	1.2	1.1	1.3	1
GR221	0.6	0.8	0.9	0.5	1.1	0.9	1	0.7
MA419	0.9	2.7	1.9	0.8	1.1	0.5	0.6	0.7
WA225	1	1.3	1.3	1.2	1.3	0.8	1.2	0.9
KE113	1.2	1.8	1.3	1.1	1.2	1.1	1.1	1
TE49	1.1	0.9	0.9	1.1	0.6	1	0.7	1
BR317	3.5	3.7	3.9	1.4	2.2	1.3	1.8	1.1
BA250	0.7	1	0.7	1.3	0.8	0.9	1	0.9
MO234	1	1.1	0.9	0.8	1.4	1	1.4	0.6
GR186	0.8	1.1	0.9	1.4	2.1	1.3	1.7	1.4
KA150	2.2	1	1.1	1.3	1	1.1	1	0.9
WI242	1	0.8	2.3	0.9	0.4	0.9	0.4	0.9
PE179	0.6	1.3	0.7	2	0.9	1.4	1	1.2
KN26	1.4	0.7	0.8	1.2	1.1	1.2	1.1	0.8
HE120	0.6	1.1	0.6	1.4	0.7	1.7	1	1.2
ZD5	1	0.7	1.3	0.9	1.2	1	0.8	1.1
FE46	1.2	0.5	0.9	1.2	1.3	1.2	1.2	1.2
CO276	1	1.2	1.1	1.2	1.5	1	1.2	1.4
GR224	2	2.8	1.6	1	0.5	0.8	0.4	0.8
BR247	0.6	0.9	0.5	0.8	1.5	0.6	1	0.6
KE105	1.3	0.6	0.9	1	0.8	1.2	1.2	1.2
MA416	1	1	1.1	1.5	1.6	1.4	1.5	1
KO136	0.9	0.6	0.6	1.1	1.5	1.1	1.5	1.5
VI32	1	0.6	0.7	0.8	0.6	0.6	0.8	0.8
SO19	1	0.5	1.4	1	1.4	1.2	1.2	1.2
OW18	0.6	0.4	0.6	1.2	1	1	0.9	1
CA258	0.8	0.7	0.9	1	1.1	0.6	0.8	0.6
TH109	1.2	1	0.7	1	1	1.2	1	1
SA176	1.4	2.1	1.4	1.4	1	1.2	1.2	1.6
KA124	1.3	1.4	1.2	1.7	1.5	1.2	1.4	1.5
OK6	0.9	1.1	0.9	1.2	1	1.4	1.4	0.9
OG5	1	1.1	1.1	1.3	1.5	1	1.5	1
RO182	1.2	1.3	1.4	1.5	1.7	1.3	1	1.3
SA160	0.8	1.3	0.9	1.2	1.1	1.2	1	1.2
TA135	1.2	0.9	0.8	0.6	0.6	0.4	0.6	0.6
HA142	0.8	1.3	1	1.3	1.2	1.4	1.4	1.2
GA161	2.8	4	2.6	0.9	1.8	1	1.4	0.8
GA164	1.8	1.4	1.9	0.9	1	1	1.1	0.8
ST238	1.2	1.8	1.2	1.5	1.4	1.5	1.4	1.4
PA212	1	1.1	0.8	1.2	1.5	1	1	1.2
HU148	3	6.4	4.5	1.1	1.7	0.8	1.2	0.8
FE60	1.8	1.3	1.3	1.4	1	1.6	1	1.4
PR96	1.6	2.5	1.4	1.5	1.5	1.4	1.6	1.2
SU68	1.2	1.2	1	1	1.5	1	1.2	1

Subjects	Labial Bone Root LL1 T120	Labial Bone Root LL2 T021	Labial Bone Root LL2 T1	Lingual Bone Root LR2 T022	Lingual Bone Root LR2 T122	Lingual Bone Root LR1 T023	Lingual Bone Root LR1 T123	Lingual Bone Root LL1 T024
WA240	0.5	0.6	0.8	0.7	0.6	0.6	0.8	0.9
BA281	0.5	0.7	1.1	3	3.8	3.6	4	2.3
BR332	1.3	1.3	1.7	3	3	3.2	3	3.2
GR221	1.5	0.8	1.3	1.7	2.4	1.7	1.8	1.4
MA419	1	0.7	1.3	2.5	1.4	3	1.5	2.6
WA225	1.1	0.7	1.1	2	1.9	1.7	1.4	1.9
KE113	1.2	0.7	1.2	3.6	3.5	3.2	2.6	3.1
TE49	0.9	1	1	2.1	1	2.8	1.9	2.9
BR317	2.5	1.2	1.9	5.9	3.4	6.5	3	6.2
BA250	1	1.3	0.9	1	0.8	1.3	0.8	1.1
MO234	1.2	0.9	1.3	2.4	1.3	1.5	1.4	1.8
GR186	1.6	1.3	1.7	1.5	1.1	1.6	1	1.4
KA150	0.6	1.5	0.8	1.6	0.8	2.3	0.6	3.3
WI242	0.6	1	0.4	0.9	2	1.1	1.6	1.2
PE179	1	1.3	1	2.6	1	1.9	1.2	2
KN26	0.8	0.9	1	2	2.2	1.4	2.1	1.4
HE120	0.8	1.5	1.1	3.6	2.7	4.3	1.9	3.9
ZD5	1.2	0.9	1.2	2.4	2.1	2.2	1.6	2.6
FE46	1	1.3	1.2	1.5	2.1	1.6	1.9	1.9
CO276	1.5	1.1	1.1	2.9	3.3	2.7	2.9	2.8
GR224	0.7	0.4	0.5	3.4	3.2	2.5	1.7	2.7
BR247	1	0.9	0.8	1.5	1.1	1.4	1	0.8
KE105	1.2	1.1	1.1	2.4	2	1.9	2.1	1.5
MA416	1.6	1.3	1.5	3.4	2.4	2.7	2.1	2.4
KO136	1.2	1.4	1.4	1.1	1.5	1.6	1.1	1.8
VI32	0.7	0.7	0.6	1.6	1.4	2.2	2.5	2.5
SO19	1	1	0.7	2.8	2.4	2.5	2.1	2.4
OW18	1	0.9	1	1.5	1	1.4	0.7	1.4
CA258	1	0.7	1.1	4.5	1.3	5.4	1.2	5.3
TH109	0.8	0.9	1	2.1	1.4	1.9	1	1.9
SA176	1	1.5	1.2	2.3	2	2.3	1.8	2.5
KA124	1.4	1.4	1.1	2.6	2.2	2.9	2.1	2.7
OK6	1.6	0.9	1.1	1.9	0.8	2.3	0.6	1.6
OG5	1.4	1.1	1.3	1.5	0.9	1.6	1.2	1.6
RO182	1.2	1.6	1.2	3.6	2.3	2.6	1.6	2.7
SA160	0.8	1	1	1.2	1.3	1	1.4	1
TA135	0.7	0.7	0.7	2.2	1.1	2.5	1.5	2.3
HA142	1.4	1.5	1	1.6	1.9	1.8	1.4	1.7
GA161	1	0.8	1.3	3.9	2.9	4.3	3.1	4.9
GA164	0.8	0.8	0.8	1.6	1.4	1.2	1.2	1.4
ST238	1.2	1.6	1.2	2.5	1.7	2.1	1.4	2.7
PA212	1.2	1	1.1	1.9	1.4	2	1.4	1.8
HU148	1.2	0.9	1.2	6	5.2	6.1	5.8	6.6
FE60	1.2	1.4	1.2	2.5	1.9	2.4	1.6	2.4
PR96	1.4	1.4	1.6	2.6	2.8	2.6	2.9	3.3
SU68	1.2	1	1.2	2.3	1.7	1.8	1.4	1.6

Subjects	Lingual Bone Root LL1 T124	Lingual Bone Root LL2 T025	Lingual Bone Root LL2 T125	Labial Bone Apex LR2 T026	Labial Bone Apex LR2 T126	Labial Bone Apex LR1 T027	Labial Bone Apex LR1 T127	Labial Bone Apex LL1 T028
WA240	0.9	0.7	0.7	1.5	1.1	1.1	1	1.1
BA281	4.2	3	4.7	1.6	1.8	1.1	0.9	1.1
BR332	3.2	3.3	3.8	3.5	3.7	4.3	4.3	4
GR221	1.7	2	2	1.9	2.1	2.4	2.3	2.3
MA419	2	2.7	2	2.8	2.3	2.6	1.9	2.7
WA225	1.6	2.2	2	2.2	2	2.6	1.6	2.9
KE113	2.6	3.5	3.3	2.1	2.2	2.1	2.5	3.3
TE49	1.5	2.4	1.3	2.1	2.3	2	2.1	2.4
BR317	3.2	5.1	4.2	2.1	2.3	2.6	2.9	2.4
BA250	1.1	1.4	0.9	1.6	1.7	1.7	1.8	1.8
MO234	1.2	1.9	1.3	1.8	1.5	2.1	1.8	1.9
GR186	1.2	1.6	1.2	2.9	2.3	3.3	2.7	3.1
KA150	2.2	1.6	1.6	3.6	3.1	4.3	3.3	3.9
WI242	1.2	1.2	1	2.8	1	3	2.2	3.4
PE179	1.2	1.5	1.4	1.6	1	1.9	1.2	1.8
KN26	1.6	1.6	1.7	2.6	2.3	3.1	2.5	2.8
HE120	2	4.2	3.6	2.8	2.6	3.6	2.7	3.1
ZD5	1.9	2.4	2.1	2.4	2.9	2.7	3.1	2.3
FE46	1.7	1.4	2.4	2.8	2.5	2.5	2.1	2.6
CO276	2.7	2.6	2.7	2.1	2.8	2.9	3.1	3
GR224	2.9	2.7	1.7	1.2	1.6	2.1	2.2	1.4
BR247	1	1.1	1	3	1.6	2.7	1.2	3.1
KE105	1.6	1.5	1.6	2.2	2.7	2.5	2.9	2.7
MA416	2.2	2.9	2.2	2.4	2.5	2.9	2.7	2.7
KO136	1.2	1.2	1.1	2.5	2.4	2.7	2.8	3.3
VI32	2.1	1.2	1.5	2.8	3	3.3	3.1	2.7
SO19	2.2	2.4	2.9	2.9	2.4	3.1	3.1	3.1
OW18	0.7	1.6	1	1.8	2.1	2.3	1.9	2.5
CA258	1.2	4.2	2.3	2.7	2.4	2	1.9	2.5
TH109	1	1.6	1.6	3.3	2.5	3.3	2.8	3.3
SA176	1.8	1.9	2.4	3	2.6	3.3	3.1	3.1
KA124	2.1	3.1	2.7	2.3	1.9	2.4	2.1	2.3
OK6	0.6	2.2	0.9	2.8	1.8	3.2	1.6	2.8
OG5	1	1.5	1	2.7	2.2	3.3	2.7	2.9
RO182	1.7	3	2.2	3.1	3.6	3.2	3.3	3.4
SA160	1.2	1.3	1.3	1.9	1.7	1.9	1.4	1.8
TA135	1.1	2.2	1.2	1.9	1.3	2.3	1.3	2.5
HA142	1.4	2.1	1.7	2.1	2.4	2.5	1.9	2.4
GA161	3	4	2.4	1.5	2.5	1.9	2.5	2

GA164	1.4	1.4	1.4	1.7	1.7	2	1.7	1.9
ST238	1.6	2.4	1.8	2.6	2.3	2.9	2.7	2.9
PA212	1.2	2	1.3	1.8	2.4	2.3	2.4	2.4
HU148	4.7	6	5.7	2.1	2.2	2.1	2.5	2.4
FE60	1.5	2.1	1.3	2.7	2.7	2.8	3.1	2.8
PR96	2.7	2.7	2.8	2.3	1.9	2.9	2.2	2.7
SU68	1.5	1.9	1.5	1.9	1.6	2	1.9	2.5

Subjects	Labial Bone Apex LL1 T128	Labial Bone Apex LL2 T029	Labial Bone Apex LL2 T129	Lingual Bone Apex LR2 T030	Lingual Bone Apex LR2 T130	Lingual Bone Apex LR1 T031	Lingual Bone Apex LR1 T131	Lingual Bone Apex LL1 T032
WA240	1.1	0.9	1.1	3	1.3	2.5	1.4	2.6
BA281	0.8	0.9	1	5.4	4.6	6.4	5	5.7
BR332	4.2	3.9	4.1	3.2	2.4	3.7	2.8	4
GR221	2.5	2.5	2.6	2.9	2.2	3	1.8	3
MA419	1.9	2.7	2.3	3.3	2.1	3.2	2.8	3.3
WA225	1.6	2.5	2	3.1	2.1	4.3	1.6	4
KE113	2.4	3	2.4	3.8	3.4	4.8	3.5	3.8
TE49	2.4	1.9	2.2	2.8	2.4	3.5	3.3	3.3
BR317	2.4	2.1	1.9	5.8	3.6	5.9	3.7	6.1
BA250	1.8	1.7	1.6	2.8	1.6	3.5	2.5	3.5
MO234	1.9	1.8	1.9	4.5	1.7	4.5	2.5	4.7
GR186	2.7	2.7	2.3	3.1	1.5	3.7	2.7	4.1
KA150	4.1	4	3.6	3.5	1.5	3.7	2.5	4
WI242	2.1	3.3	1.4	2.8	2.7	4.1	4.1	4.1
PE179	1.2	1.7	1.2	3	1.6	2.5	1.9	3.1
KN26	2.7	2.2	2.7	3.8	4	4.6	4	4.1
HE120	3.7	3.1	2.5	3.8	3.7	3.9	3.9	4.1
ZD5	3.2	1.8	2.7	2.7	1.9	2.7	2.2	2.9
FE46	2.3	2.4	2.7	2.6	2.8	3.3	2.7	3.2
CO276	2.9	2.8	3.1	2.6	3.2	3.3	3.7	3.3
GR224	2	1.9	1.9	3.6	3.6	3.5	3.9	3.9
BR247	1.5	2.5	1.2	1.7	1.7	3.1	1.3	2.1
KE105	3	2.2	2.7	3.1	2.6	3.1	2.5	2.7
MA416	3	2.6	2.5	3.4	3.2	4.3	3.3	4.2
KO136	2.9	2.5	2.7	2.9	1.8	3.5	2.2	3.8
VI32	3.5	2.6	2.7	4.5	2.1	5.5	3.5	5.5
SO19	2.4	3.1	2.5	3.3	3.7	2.9	3.3	3.1
OW18	1.8	2	1.7	3.2	1	3.7	1	3.9
CA258	2.4	2.2	2.6	6.3	3.4	7.8	4.2	7.6
TH109	2.8	2.9	2.3	3.1	1.7	4.9	3.4	4.9
SA176	3.3	3	2.7	2.7	2	3.5	3.1	3.5
KA124	1.9	2.7	1.8	3.7	3	3.5	3.1	3.4
OK6	2	2.6	1.8	3.2	2	4.4	1.4	4.2
OG5	2.5	2.6	2.2	2.9	1.6	3.1	2.4	2.9
RO182	3.8	2.7	3.7	2.5	2.5	2.4	2.6	2.3
SA160	1.5	2	1.2	1.8	0.9	2.1	1.2	2.4
TA135	1.1	2.1	1.3	4.6	2.3	5.7	3.5	5.6
HA142	1.9	2.3	2.3	2.5	2.7	2.9	2.9	3

GA161	3	2	2.4	6.4	3.7	7.9	6.2	7.5
GA164	1.7	1.7	1.7	3	2.7	3.3	2.7	3.5
ST238	2.7	2.6	2.2	4.1	4.2	4.9	4.6	5
PA212	2.4	2	2.3	3.4	1.7	3.7	1.2	3.9
HU148	2.3	2	2.1	6.5	5.8	7.1	6.6	6.9
FE60	3.1	2.3	2.5	3.5	3	4.1	3.9	3.5
PR96	2.3	2.4	1.6	4.4	5.2	5.8	6.6	5.3
SU68	1.7	1.7	1.9	3.2	2.1	2.9	2.3	2.9

Subjects	Lingual Bone Apex LL1 T132	Lingual Bone Apex LL2 T033	Lingual Bone Apex T133	Inter-canine Cusp T034	Inter-canine Cusp T134	Inter-canine Cusp T21	Inter-canine CEJ T035	Inter-canine CEJ T135
WA240	1.3	2.5	1.3	18.6	26.5	26	23.2	26.7
BA281	4.9	4.9	5.9	24.5	26.9	27.1	23.3	24.3
BR332	2.7	3.4	2	24.6	24.8	24.6	23.1	24.2
GR221	2.2	2.9	2.4	25.7	26.1	25.8	25.3	26
MA419	2.9	3.4	2.4	25.6	24.9	24.9	24.9	24.6
WA225	1.6	3.5	2	28.1	28.2	28.1	26.3	27.6
KE113	3.6	4.1	3.8	23.8	24	23.8	22.3	23.3
TE49	3.1	2.9	3.7	22.5	23.1	22.7	21.7	22.9
BR317	4.4	6	4.3	29.1	29.1	28.9	25.3	25.6
BA250	2.5	2.7	2.2	25	25.8	25.8	24.2	25.3
MO234	3.1	4.4	3.4	22.2	23.8	23.8	21.7	23.7
GR186	2.9	3.5	1.9	24	25	23.6	22.6	23.7
KA150	2.7	3.6	1.2	27.1	28	27.3	23.5	25.1
WI242	4.1	3.5	2.7	25.5	25.9	25.8	21.9	22.3
PE179	1.3	2.8	2.4	24.4	24.7	24.7	23.8	24.8
KN26	3.5	3.6	3.5	25.3	25.3	25.3	23.8	24.5
HE120	3.6	3.9	3.8	23.4	24.9	24.2	23	24.6
ZD5	1.6	2.8	1.6	22	23.5	23.5	21.9	23.1
FE46	2.5	1.7	2	25.3	26	25.8	21.1	25.3
CO276	3.3	3.5	3.2	25.8	28.2	27.2	23.2	25.5
GR224	3.8	3.7	4.2	27.9	27.1	27.1	25.8	26.4
BR247	1.4	1.8	1.6	22	25.5	23.8	22.3	26.5
KE105	2.1	3.3	2.4	28.7	27.4	27.4	23.2	23.9
MA416	3.1	3.7	3.5	22.9	25.4	24.7	23.6	25
KO136	2.3	2.7	1.1	22.1	23.5	23.5	22.9	23.8
VI32	3.3	5	2.6	24.3	25.5	25	21.2	24.3
SO19	3.1	2.8	3.3	24.8	25.2	24.9	22.4	23.8
OW18	1	3.3	1	25.4	26.4	26.4	24.1	26.1
CA258	4.6	6.8	4.7	20.2	26.3	25	19.9	25.8
TH109	3.4	3.4	2.6	27.1	27.1	27	24.6	26.3
SA176	3.2	2.9	2.4	26.9	28.2	28.2	24.2	25.1
KA124	2.9	3.7	3	28.7	26.7	26.7	25.5	24.9
OK6	1.7	3.3	1.4	28.3	28.7	27.8	26.3	27.4
OG5	2.3	2.7	1.8	25.7	24.6	24.9	24.7	25.4
RO182	2.6	2.1	2.4	26.6	26.5	27.3	23.8	25.6
SA160	0.8	2.1	1.2	25.2	25.4	25.3	24.6	25.7
TA135	3.1	4.7	2	26	27.7	27.6	24.7	25.9
HA142	2.9	2.7	2.8	27.5	25.1	24.9	25.5	25.1

GA161	6.2	5.9	5.4	25.4	28.2	27.4	22.6	23.8
GA164	2.9	2.3	2.4	26.1	27.9	27.9	23.1	24.3
ST238	4.5	3.8	3.9	26	24.6	24.4	24.7	24
PA212	1.2	3	1.7	25.1	25.1	24.8	22.4	24.9
HU148	6.4	5.4	4.9	28.5	26.5	26.7	25.1	25
FE60	3.9	3.8	2.5	25.5	26.8	26.8	23.4	24.7
PR96	6.6	4.2	5.1	33.4	30.5	30.3	26.8	26.7
SU68	2.5	2.7	1.8	26.2	27.3	27.1	23.7	27.3

Subjects	Inter-canine Apex T036	Inter-canine Apex T136	Arch length discrepancy T037	Arch length discrepancy T137	Arch length discrep-ancy T22	IMPA T040	IMPA T138
WA240	17.5	22.5	-5.2	0.2	-0.3	95	92.5
BA281	16.9	20.8	-0.1	0.3	-1.3	94.4	99.7
BR332	20.2	21.8	-1	0.2	-0.2	86.2	92.1
GR221	21.8	24.2	-0.8	0.3	-0.4	81.4	91.2
MA419	17.8	20.8	7.7	0.7	3	98	94.7
WA225	24.1	26.7	-1.7	0.2	-0.1	85.7	86.4
KE113	20.4	21.6	-2.6	0.4	-0.3	93.9	101.7
TE49	18.6	19.2	4.5	0.1	0	95.1	95.8
BR317	18.8	20.7	3.2	-0.1	0.4	115.2	117
BA250	20.3	25.3	-1.5	0.1	-0.3	78.6	85.3
MO234	19.5	22.7	-2.8	-0.1	-0.2	93	95.9
GR186	20.7	23.3	-2.3	-0.8	-1.5	96.6	98.3
KA150	19.6	23	-1.5	-0.3	-0.5	92.1	98.3
WI242	18.9	19	-1	0.1	-3.1	90.5	96.1
PE179	23	24.6	-0.4	-0.4	-0.7	91.1	86.6
KN26	18.3	19.3	-1.4	-0.4	-1.3	100.9	93.3
HE120	19.9	21.8	3.2	0.6	0.4	89.5	91
ZD5	19.6	23.3	-0.1	1	0.4	89.2	85.8
FE46	19.7	24.9	-0.1	0.6	0.2	95.5	97.1
CO276	17.8	20.2	-4.3	-0.1	-0.8	87.9	93
GR224	20.9	23.6	-3.8	-0.5	-1.3	91.3	93.7
BR247	22.7	27.8	-8	-0.1	-0.5	93.4	84.9
KE105	19.5	18.4	-5.5	-0.1	-0.5	87.8	95.4
MA416	22.6	23.6	-2.4	0	-0.8	90.7	103.4
KO136	21	24.4	-0.8	0	-0.2	89.3	86.1
VI32	17.8	21.8	-1.6	-0.3	-0.4	82.5	94.3
SO19	18.9	21.7	0.2	0	0	87.7	93.8
OW18	21.2	25.5	-0.9	-0.1	-0.2	85.3	85.8
CA258	20.5	27.3	-6.1	0	-1.2	106.9	94.6
TH109	21.9	24.8	-4.2	0	-0.3	88.9	99.7
SA176	20.7	20.9	-0.6	0	0	98.4	102
KA124	21	21.1	2.9	0	0	93.9	96.8
OK6	16.8	22.8	-3.1	0	-1	78.8	83.6
OG5	22.9	25.1	0.5	0	0	75.2	78.9
RO182	19.9	24.2	-0.3	0	-0.3	88.1	96.7
SA160	23	27.6	-1.7	0	-0.1	87.7	89.7
TA135	20.4	22.3	-3.5	0	0	87	94.3
HA142	22.7	25.5	1.9	0	-0.4	94.5	91.4

GA161	18	18.2	-1.1	0	-0.7	102.5	101.9
GA164	15.9	19.4	-2.5	0	-2.1	91	99.7
ST238	18.7	23.2	2.6	0	0	94.1	90.1
PA212	21.1	24.7	-1.1	0	0	93.1	91.9
HU148	19.6	22	1.8	0	-0.5	106.8	103.9
FE60	19.7	21.3	-1.5	0	-0.1	95.3	99.7
PR96	20.3	22.7	4.4	0	0	104.6	86.9
SU68	20	26.1	-3.5	0	-0.3	93.7	89.1

Repeated Measurements

Subjects	CEJ LR2-LR1 T01R	CEJ LR2-LR1 T11R	CEJ LR1-LL1 T02R	CEJ LR1-LL1 T12R	CEJ LL1-LL2 T03R	CEJ LL1-LL2 T13R	ROOT LR2-LR1 T04R
BA281	0.7	1.8	1.2	1	1.3	1.5	1
GR221	1.2	1.2	1.4	1.2	1.2	1.5	2.1
GR186	1.1	1.1	1	1.5	1.1	1.1	1.4
WI242	0.8	0.8	0.5	0.6	0.5	0.8	0.7
CO276	1.4	1.6	1.4	1.6	1.1	1.2	1.2
MA416	1.2	1.2	1.2	1	1.3	1.2	1.2
CA258	0.6	1.5	0.4	1.5	1.2	1.1	0.8
OG5	1	1.7	1	1	1.2	1.7	1
TA135	0.8	1.2	1.6	1.3	0.8	1.4	0.6
ST238	1.5	1	1	1.2	1.2	1.6	1.3

Subjects	ROOT LR2-LR1 T14R	ROOT LR1-LL1 T05R	ROOT LR1-LL1 T15R	ROOT LL1-LL2 T06R	ROOT LL1-LL2 T16R	Apex LR2-LR1 T07R	Apex LR2-LR1 T17R
BA281	1.3	1.4	1.1	1	2.1	1.4	2.4
GR221	1.2	1.6	1.7	1.4	1.8	1.8	1.9
GR186	1.4	1.2	1.6	1.2	1.2	1.5	1.7
WI242	0.8	0.5	0.6	0.5	0.4	0.7	0.9
CO276	1.6	1.6	1.6	0.6	1	1.3	1.5
MA416	1.4	1.5	1.2	1.2	1.4	2	2.2
CA258	0.6	0.6	1.6	1.2	1	1	0.9
OG5	1.9	1.6	1.6	1.2	1.8	1.8	2.7
TA135	1.2	1.7	1.1	1.2	1.6	1.1	1.6
ST238	1	1.2	1.6	1	1.4	2.1	1.4

Subjects	Apex LR1-LL1 T08R	Apex LR1-LL1 T18R	Apex LL1-LL2 T09R	Apex LL1-LL2 T19R	Labial Bone CEJ LR2 T010R	Labial Bone CEJ LR2 T110R	Labial Bone CEJ LR1 T011R
BA281	1.5	2.4	1.6	3.1	0.7	0.3	0.5
GR221	3.5	2.5	2.1	1.9	0.7	0.3	0.5
GR186	1.6	1.5	1.4	1.2	1	1.2	0.8
WI242	0.5	1.4	0.7	0.8	0.8	0.5	0.9
CO276	1.2	1.2	0.6	1.2	0.6	0.6	1
MA416	1.7	1.4	1.8	1.4	0.4	0.9	1.2
CA258	1.4	2.5	0.4	1.2	0.6	0.5	1.6
OG5	2.2	2.4	1.5	3	0.6	0.6	0.4
TA135	1.2	1.5	0.8	1.8	0.2	0.3	0.6
ST238	1.2	1.4	0.7	1.2	0.7	0.8	0.6

Subjects	Labial Bone CEJ LR1 T111R	Labial Bone CEJ LL1 T012R	Labial Bone CEJ LL1 T112R	Labial Bone CEJ LL2 T013R	Labial Bone CEJ LL2 T113R	Lingual Bone CEJ LR2 T014R	Lingual Bone CEJ LR2 T114R
BA281	0.2	0.7	0.2	0.7	0.4	1	0.7
GR221	0.3	0.5	0.2	1	0.5	0.8	0.7
GR186	0.8	0.8	1	1	0.8	1	1
WI242	0.6	0.9	0.6	0.9	0.6	0.8	1.5
CO276	0.6	1.1	0.8	0.8	0.9	1.5	1.4
MA416	1	0.4	0.8	0.6	0.7	1.5	0.9
CA258	0.5	0.4	0.6	0.8	0.6	2.2	0.8
OG5	0.8	0.6	0.6	0.4	0.7	1.1	1.1
TA135	0.6	0.8	0.9	1	0.7	1.3	1.1
ST238	0.6	0.4	0.8	0.7	0.6	1.3	1.1

Subjects	Lingual Bone CEJ LR1 T015R	Lingual Bone CEJ LR1 T115R	Lingual Bone CEJ LL1 T016R	Lingual Bone CEJ LL1 T116R	Lingual Bone CEJ LL2 T017R	Lingual Bone CEJ LL2 T117R	Labial Bone Root LR2 T018R
BA281	1.3	1.2	1.1	0.5	1.4	0.9	1
GR221	0.7	0.5	0.7	0.7	0.8	0.9	0.5
GR186	1	1	1.2	0.8	1.1	0.9	1.4
WI242	0.9	1.2	1	1	0.8	2.3	0.9
CO276	1.4	1.4	1.4	1	1.2	1.1	1.2
MA416	0.6	1	0.8	1	1	1.1	1.5
CA258	0.6	0.9	1.7	0.8	0.7	0.9	1
OG5	1.4	1	1.2	1	1.1	1.1	1.3
TA135	1.6	1.1	1	1.2	0.9	0.8	0.6
ST238	1.6	1	2.1	1.2	1.8	1.2	1.5

Subjects	Labial Bone Root LR2 T118R	Labial Bone Root LR1 T019R	Labial Bone Root LR1 T119R	Labial Bone Root LL1 T020R	Labial Bone Root LL1 T120R	Labial Bone Root LL2 T021R	Labial Bone Root LL2 T1R
BA281	1.2	0.5	0.8	0.9	0.5	0.7	1.1
GR221	1.1	0.9	1	0.8	1.5	0.8	1.3
GR186	2.1	1.3	1.7	1.4	1.6	1.3	1.7
WI242	0.4	0.9	0.4	0.9	0.6	1	0.4
CO276	1.5	1	1.2	1.4	1.5	1.1	1.1
MA416	1.6	1.4	1.5	1.1	1.6	1.3	1.5
CA258	1.1	0.6	0.8	0.6	1	0.7	1.1
OG5	1.5	1	1.5	1	1.4	1.1	1.3
TA135	0.6	0.4	0.6	0.6	0.7	0.7	0.7
ST238	1.4	1.5	1.4	1.4	1.2	1.6	1.2

Subjects	Lingual Bone Root LR2 T022R	Lingual Bone Root LR2 T122R	Lingual Bone Root LR1 T023R	Lingual Bone Root LR1 T123R	Lingual Bone Root LL1 T024R	Lingual Bone Root LL1 T124R	Lingual Bone Root LL2 T025R
BA281	3.1	3.8	3.6	4	2.2	4.2	3
GR221	1.7	2.4	1.7	1.8	1.4	1.7	2
GR186	1.5	1.1	1.7	1	1.4	1.2	1.6
WI242	0.9	2	1.1	1.6	1.2	1.2	1.2
CO276	2.9	3.3	2.7	2.9	2.8	2.7	2.6
MA416	3.4	2.2	2.7	2.1	2.4	2.2	2.9
CA258	4.5	1.3	5.4	1.2	5.3	1.2	4.2
OG5	1.5	0.9	1.6	1.2	1.6	1	1.5
TA135	2.2	1.1	2.5	1.5	2.3	1.1	2.2
ST238	2.5	1.7	2.1	1.4	2.7	1.6	2.5

Subjects	Lingual Bone Root LL2 T125R	Labial Bone Apex LR2 T026R	Labial Bone Apex LR2 T126R	Labial Bone Apex LR1 T027R	Labial Bone Apex LR1 T127R	Labial Bone Apex LL1 T028R	Labial Bone Apex LL1 T128R
BA281	4.7	1.6	1.8	1.1	0.9	1.1	0.8
GR221	2.1	1.9	2.1	2.4	2.3	2.3	2.5
GR186	1.2	2.9	2.3	3.3	2.7	3.1	2.7
WI242	1	2.8	1	3	2.2	3.4	2.1
CO276	2.7	2.1	2.8	2.9	3.1	3	2.9
MA416	2.2	2.4	2.5	2.9	2.7	2.7	3
CA258	2.3	2.7	2.4	2	1.9	2.5	2.4
OG5	1	2.7	2.2	3.2	2.7	2.9	2.5
TA135	1.2	1.9	1.3	2.3	1.3	2.5	1.1
ST238	1.8	2.6	2.3	2.9	2.7	2.9	2.7

Subjects	Labial Bone Apex LL2 T029R	Labial Bone Apex LL2 T129R	Lingual Bone Apex LR2 T030R	Lingual Bone Apex LR2 T130R	Lingual Bone Apex LR1 T031R	Lingual Bone Apex LR1 T131R	Lingual Bone Apex LL1 T032R
BA281	0.9	1	5.5	4.6	6.4	5	5.7
GR221	2.5	2.6	2.9	2.2	3	1.8	3
GR186	2.7	2.3	3.1	1.5	3.7	2.7	4.1
WI242	3.3	1.4	2.8	2.7	4.1	4.1	4.1
CO276	2.8	3.1	2.6	3.3	3.3	3.7	3.3
MA416	2.6	2.7	3.4	3.2	4.3	3.3	4.2
CA258	2.2	2.6	6.3	3.4	7.8	4.2	7.6
OG5	2.6	2.2	2.9	1.6	3.1	2.4	2.9
TA135	2.1	1.3	4.6	2.3	5.7	3.5	5.6
ST238	2.6	2.1	4.1	4.2	4.9	4.6	5

Subjects	Lingual Bone Apex LL1 T132R	Lingual Bone Apex LL2 T033R	Lingual Bone Apex T133R	Inter-canine Cusp T034R	Inter-canine Cusp T134R	Inter-canine Cusp T21R	Inter-canine CEJ T035R
BA281	4.9	4.9	5.9	24.5	26.9	27.1	23.3
GR221	2.2	2.9	2.4	25.8	26.1	25.8	25.3
GR186	2.9	3.5	1.9	24	25	23.6	22.6
WI242	4.1	3.5	2.7	25.5	25.9	25.8	21.9
CO276	3.3	3.5	3.2	25.8	28.2	27.2	23.2
MA416	3.1	3.7	3.5	22.9	25.4	24.7	23.6
CA258	4.6	6.8	4.7	20.2	26.3	25	19.9
OG5	2.3	2.7	1.8	25.7	24.6	24.9	24.7
TA135	3.1	4.7	2	26	27.7	27.6	24.7
ST238	4.5	3.8	3.9	26	24.6	24.4	24.7

Subjects	Inter-canine CEJ T135R	Inter-canine Apex T036R	Inter-canine Apex T136R	Arch length discrepancy T037R	Arch length discrepancy T137R	Arch length discrepancy T22R
BA281	24.3	16.9	20.8	-0.1	0.3	-1.3
GR221	26.1	21.8	24.2	-0.8	0.3	-0.4
GR186	23.7	20.7	23.2	-2.3	-0.8	-1.5
WI242	22.3	18.9	19	-1	0.1	-3.1
CO276	25.5	17.9	20.2	-4.3	-0.1	-0.8
MA416	25	22.6	23.6	-2.4	0	-0.8
CA258	25.8	20.5	27.3	-6.1	0	-1.2
OG5	25.4	23	25.1	0.5	0	0
TA135	25.9	20.4	22.3	-3.5	0	0
ST238	24	18.7	23.2	2.6	0	0

Subjects	IMPA T040R	IMPA T138R
BA281	94.4	99.7
GR221	81.4	91.2
GR186	96.6	98.3
WI242	90.5	96.1
CO276	87.9	93
MA416	90.7	103.4
CA258	106.9	94.6
OG5	75.2	78.9
TA135	87	94.3
ST238	94.1	90.1

Correlation Coefficients

Subjects	Crowding	Average Interdental Bone	Average Labial Bone	Average Lingual Bone
WA240	-0.3	1.03	0.09	-0.65
BA281	-1.3	0.75	0.04	0.35
BR332	-0.2	0.25	0.19	-0.51
GR221	-0.4	-0.23	0.30	-0.26
MA419	3	0.00	-0.14	-0.86
WA225	-0.1	0.45	-0.24	-1.06
KE113	-0.3	-0.03	-0.03	-0.45
TE49	0	0.92	-0.04	-0.56
BR317	0.4	0.03	0.46	-2.21
BA250	-0.3	1.12	-0.08	-0.61
MO234	-0.2	-0.68	0.19	-1.23
GR186	-1.5	0.05	-0.04	-0.88
KA150	-0.5	0.47	-0.39	-1.31
WI242	-3.1	0.22	-0.96	0.06
PE179	-0.7	0.27	-0.55	-0.93
KN26	-1.3	0.10	-0.08	0.01
HE120	0.4	0.43	-0.41	-0.81
ZD5	0.4	0.53	0.40	-0.71
FE46	0.2	1.18	-0.11	0.11
CO276	-0.8	0.27	0.21	0.16
GR224	-1.3	0.57	0.03	-0.13
BR247	-0.5	1.77	-0.55	-0.43
KE105	-0.5	0.60	0.19	-0.33
MA416	-0.8	-0.08	0.14	-0.63
KO136	-0.2	0.63	0.04	-0.79
VI32	-0.4	0.78	0.09	-1.03
SO19	0	0.07	-0.24	0.10
OW18	-0.2	0.67	-0.16	-1.58
CA258	-1.2	0.40	0.13	-3.13
TH109	-0.3	0.28	-0.34	-0.96
SA176	0	0.43	-0.25	-0.36
KA124	0	0.18	-0.30	-0.56
OK6	-1	1.30	-0.44	-1.71
OG5	0	0.68	-0.08	-0.70
RO182	-0.3	0.55	0.18	-0.41

SA160	-0.1	0.50	-0.31	-0.45
TA135	0	0.38	-0.44	-1.75
HA142	-0.4	-0.23	-0.15	-0.08
GA161	-0.7	0.05	0.63	-1.49
GA164	-2.1	0.73	-0.04	-0.23
ST238	0	0.08	-0.24	-0.48
PA212	0	0.30	0.18	-1.33
HU148	-0.5	0.62	0.28	-0.69
FE60	-0.1	0.05	-0.08	-0.59
PR96	0	0.42	-0.21	0.63
SU68	-0.3	1.50	0.01	-0.54
Average	-0.38	-0.08	0.17	-0.13