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Randa Zarka

Candidate for the degree Master of Science

in Dentistry.

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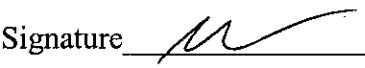
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CWRU School of Dentistry
Department of Orthodontics
10900 Euclid Avenue
Cleveland, Ohio 44106-4905

Buccal bone thickness of maxillary first molars before and after orthodontic archwire expansion.

by

Randa Zarka D.D.S.

Submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry

Thesis Advisor:

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

Committee Members:

Sebastian Baumgaertel, D.M.D., M.S.D.
Leena Palomo, D.D.S., M.S.D.
Juan Martin Palomo, D.D.S., M.S.D.

Department of Orthodontics

School of Dental Medicine

Case Western Reserve University

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DEDICATION

In memory of my father, Nofal, whose presence in my life guided me, as much as his absence drove me, to do better and be better.

To my mother, Riad, who has sacrificed her life for her children, and continues to do so everyday.

To my sister, Lena, a prosthodontist who spends her days restoring and replacing teeth, yet inspired me to straighten them instead.

To my brothers, Ziad, Mohammad, and Mustafa, who care for me and protect me, like only brothers do.

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BUCCAL BONE THICKNESS OF MAXILLARY FIRST MOLARS BEFORE AND AFTER ORTHODONTIC ARCHWIRE EXPANSION.

Abstract
By
RANDA ZARKA

When orthodontists expand intermolar width is there a decrease in buccal bone support or does this buccal tooth movement induce bone formation? The aim of this study was to detect the effects of modest amounts of orthodontic arch wire expansion on buccal alveolar bone thickness covering the mesial and distal roots of the maxillary first molars.

Sixty patients treated with a full course of edgewise pre-torqued pre-angulated brackets were evaluated. The expansion group (n=30) consisted of patients who had ≥2mm increase in intermolar width (range = 2.0-3.9 mm). This group was matched on sex, age, and treatment time to patients who had <2mm increase in intermolar width; the non-expansion group (n=30). Pre and post-treatment intermolar widths and alveolar bone thickness of the maxillary first molar roots were measured using a commercially available software program: (OnDemand3D, CyberMed, Seoul, Korea).

The results were as follows. Before treatment the expansion group had a mean mesiobuccal bone thickness of 1.68±0.6 mm and distobuccal bone thickness

of 2.29±0.6 mm. The non-expansion group had a mean mesiobuccal bone thickness of 1.30±0.5 mm and distobuccal bone thickness of 2.20±0.5 mm. After treatment the mean buccal alveolar bone present on the mesial and distal roots was 1.42±0.5 and 2.26±0.6 for the expansion group and 1.29±0.5 and 2.20±0.5 for the non-expansion group. Only the difference in mesiobuccal bone width in the expansion group was statistically significant ($P \leq 0.05$).

We conclude therefore that modest archwire expansion of the first molars (up to 2mm per side) appears to be accompanied by deposition of buccal bone. Distobuccal rotation of the maxillary molars reduces buccal bone support on the mesial buccal root.

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REVIEW OF THE LITERATURE

Maxillary expansion in growing patients can be achieved dentally (orthodontic expansion), skeletally (orthopedic expansion), or a combination of both. The decision to do one or the other depends on the anatomic basis of the problem. The primary indication for rapid palatal expansion is a true skeletal maxillary deficiency in the transverse plane of space (Proffit et al 2000). The indications for arch wire expansion tend to be less clear but primarily include one of two classes of patients: those in whom transverse deficiency is minimal, and those in whom an increase in arch perimeter is needed.

Orthopedic expansion utilizes a fixed or removable appliance to apply a sufficient enough force to result in the separation of the right and the left maxillary palatal shelves at the level of the midpalatal suture. Although ideally orthopedic expansion would only result in the aforementioned skeletal effects; it has been repeatedly established that orthodontic side effects, namely buccal tipping of the posterior teeth, is a consistent finding. In growing patients, the ratio of skeletal expansion to dental expansion ranges from 35%-58% (Will et al 2000, Ladner et al 1995).

Orthodontic expansion may be achieved by arch wires engaging pre-torqued brackets of the teeth, hence; the term arch wire expansion (Gill et al 2004). In contrast to skeletal expansion, dental expansion results primarily from buccal

tipping of the maxillary posterior teeth, as arch wires do not supply sufficient enough force for mid-palatal suture opening (Haas 1970).

The first of two primary indications for arch wire expansion is to increase arch perimeter. Orthodontic expansion of the dental arches to alleviate crowding dates back to Dr. Edward Angle for whom proper orthodontic treatment for almost every patient involved expansion of the dental arches sans extraction. Trends in orthodontics have cycled since then. The 1940's ushered in the era of Tweed orthodontics and with it a growing inclination towards extraction treatment and a growing emphasis on maintenance of pre-orthodontic intercanine and intermolar widths. In recent years, however, expansion non-extraction trends have been once again growing in popularity. The relationship between expansion and non-extraction treatment is the following: orthodontists use expansion to gain arch perimeter and thereby avoid extractions. This results in a directly proportional relationship between the frequency of expansion and the extraction trends du jour. One of the biggest controversies in orthodontics today, whether or not to extract teeth, is in actuality a controversy that dates back to the early 1900's.

Expansion refers to an increase in the transverse dimensions of the arches. This is typically measured via changes in intercanine and intermolar widths. In cases in which space creation is necessary, the only way to achieve this, sans extraction, is via one or more of the following: extraoral traction, interproximal reduction (stripping), and arch expansion (O'Higgins et al 2000). In other words, expansion can be used to relieve space deficiency.

That orthodontic expansion, measured via an increase in intermolar width, results in an increase in arch perimeter, has been corroborated numerous times. To date, however, different amounts of arch perimeter changes have been proposed for the same amount of orthodontic expansion. O'Higgins et al. (2000) found a 0.6 mm increase, Germane et al. (1991) found a 0.93 mm increase, and Hnat et al. (2000) found a 0.9 mm increase in arch perimeter for every 1 mm increment of increase in intermolar width. Most recently, using a computer generated model and program, Noroozi et al. (2002) found that each one millimeter of intermolar expansion increases the arch perimeter approximately 0.3 mm. As seen above, although the amount of arch perimeter increases expected with arch expansion ranges, the predominant conclusion is consistent: the former is influenced by the latter.

The second of two primary indications for arch wire expansion is in patients in whom transverse deficiency is minimal. This typically manifests in the form of a maxillary arch constricted enough to require "rounding out" of the arch form, but not constricted enough to require skeletal expansion. Arch form refers to the general shape of the dental arch. Over the years, there have been different geometric and mathematical models used to describe arch forms, but the most enduring has been Ricketts classification of arch form in untreated subjects into one of five arch forms: normal, ovoid, tapered, narrow ovoid, and narrow tapered (Ricketts 1989).

Taner et al. (2004) used these arch forms to evaluate the changes in the dental arch width and form resulting from non-extraction, non-RPE, orthodontic treatment. Twenty-one dental plaster models were scanned and evaluated using a

computerized method. They found that the distances between all maxillary teeth increased as a result of treatment. This increase was stable, as the maxillary arch form changes were statistically insignificant three years post retention. Furthermore, in evaluating pretreatment casts, they found that 76% of pretreatment maxillary arch forms classified as tapered or narrow tapered. Interestingly, 93% of these tapered and narrow tapered arches were changed to normal or ovoid arches post-treatment. However, this study utilized a relatively small sample, and, more importantly, casts were evaluated a relatively short time post-treatment with only three years of retention.

Proper maxillary arch form is necessary for proper interdigitation with the opposing mandibular arch. The maxillary and mandibular arch forms should be harmonious with one another, and if there is a discrepancy between them before orthodontic treatment, the mandibular arch form should be used as a guide. Not only is a proper maxillary arch form functionally important, but also esthetically. Roden-Johnson et al. (2005) found that when dentists and orthodontists were asked to use a visual analogue scale to rate the photographs of twenty orthodontically treated women in smile, both groups perceived the broader arch forms to be more esthetic.

Arch form also changes with age sans orthodontic treatment. These arch form changes namely result from arch width increases which are most significant in the molar area (Harris 1997). In fact, numerous studies have shown that intermolar width increases naturally with age. Bishara et al. (1997) reported the changes in dental arch width from age 6 weeks to 45 years and found that intermolar widths

increased significantly between 3 and 13 yrs of age in untreated patients. Marshall et al. (2003) found that maxillary intermolar width measured at the level of the first molar increases from the age of 7.5 to 26.4. Other longitudinal studies have corroborated the above finding; maxillary intermolar width measured at the level of the first molars increases with age (Snodell et al 1993, DeKock 1972).

It is important to delve into the scientific basis behind tooth movement; i.e. when we place arch wires, how does this translate into tooth movement resulting in orthodontic expansion. There are two commonly accepted theories on the biology of tooth movement.

The first is the piezoelectric theory first proposed by Bassett and Becker in 1962. This theory proposes that orthodontic forces applied to a tooth are transmitted to the tissues surrounding it generating a piezoelectric signal. Mechanical forces applied to teeth result in the bending of the adjacent alveolar bone which induces the hydroxapatite crystals to generate an electric current that acts as a stimulus for bone deposition and resorption. More specifically, this bone bending results in concave surfaces under compression to develop an electronegative potential in which deposition via osteoblastic activity occurs, and convex surfaces under tension to develop an electropositive potential in which resorption via osteoclastic activity occurs.

The second and most commonly accepted theory of orthodontic tooth movement was proposed by Schwartz in 1932 and is commonly known as the pressure-tension theory. This theory postulates that application of sufficient force on

a tooth results in a pressure side, in the direction of force application, and a tension side opposing it. This hypothesis in its simplest form states that bone resorption occurs on the pressure side and bone deposition on the tension side. The result of this remodeling causes tooth movement to occur.

Previously, the pressure tension theory has been used as an explanation for why bone dehiscence may occur in response to orthodontic expansion. This theory, when applied to the periodontal ligament, would suggest that the application of buccally directed force on the posterior maxillary dentition, such as that which is applied in arch wire expansion, will result in resorption of bone on the buccal (the pressure side), and deposition of bone on the lingual (the tension side).

Verna et al. 1999 states "studies have focused (only) on the reaction within the periodontal ligament," and for the most part ignored the surrounding structures. In actuality, the pressure-tension theory does not refute the potential for alveolar buccal bone deposition in response to facially directed forces such as those applied via orthodontic expansion, why? Because not only does pressure and tension in the periodontal ligament incite bone resorption and deposition; respectively, but also pressure and tension in the periosteum overlying the bone.

Orthodontic tooth movement results in wide spread tissue reactions, and are not localized only to the periodontal ligament. Although facially directed forces on a tooth result in pressure in the buccal periodontal ligament, they also result in tension in the periosteum overlying the buccal alveolar bone. Thilander (1995) found that this periosteum, when exposed to tension, has the potential to initiate bone formation

and deposition. Periosteum is made of connective tissue and contains progenitor cells which have the capacity to develop into osteoblasts responsible for bone formation. The osteogenic potential of periosteal bone formation continues throughout life, although this rate decreases with age. In confirmation of this application of the pressure-tension theory, Ohshima et al (1972) and Ogihara et al (2003) found that lateral expansion did result in new bone formation at the periosteal surface.

Ogihara et al (2003) evaluated the histological changes of alveolar bone in response to lateral expansion in the mandible arch. A fixed modified Schwartz appliance was fabricated for twenty-four Westar rats age fourteen weeks old. All the Schwartz appliances were adjusted to consistently apply 10 grams of initial load. The appliance was left in the mouth for a period of 1, 5, 7 or 14 days. The amount of resultant lateral expansion was determined by measuring the difference between the initial and final distance between the central pits of the right and left first molars. The rats were then sacrificed, the mandibles removed, and the alveolar bone surrounding the first molar was excised and sectioned. These sections were fixed, stained, and then evaluated under light microscopy. The average amount of lateral expansion after 14 days was 1.06 mm.

They found deposition of new bone on the periosteal surface of the buccal alveolar bone and the periodontal surface of the lingual alveolar bone with a corresponding resorption of bone on the periodontal surface of the buccal alveolar bone and the periosteal surface of lingual alveolar bone. Although Ogihara et al

(2003) exclusively studied the mandibular arch, it can be inferred that the maxillary and mandibular periosteum respond in a similar fashion.

Limitations to this study include the fact that the sample size was small (24 rats), as was the amount of resultant expansion (1.06 mm). No reference was made to the rate of dissipation of the force applied by the Schwartz appliance, rendering comparisons to the forces applied by arch wire expansion impossible. Furthermore, the nature of the force application of the Schwartz appliance differs from that of lateral expansion achieved via arch wires in that this appliance only places forces on the first molars, and forces are not distributed across the dental arch. Finally, this was a study of rats, and as in all animal studies, its application to human anatomy is uncorroborated.

Verna et al. (1999) also performed a study on rats to histologically assess the effects of orthodontic tooth movement on the surrounding alveolar bone. Fifty-four adult male Wistar rats underwent orthodontic tooth movement of the maxillary first molar using a closed coil spring which applied a constant mesiobuccal force of 50 grams for a period of 4, 7, and 14 days. These animals were subsequently injected with oxytetracycline, a new bone apposition marker, 48 hours before they were euthanized. The maxilla was subsequently sectioned at the cervical, intermediate, and apical levels of the maxillary first molar root. Sections of the surrounding alveolar bone were fixed, stained and microscopically analyzed.

Similar to the findings of Ogihara et al (2003) enhanced osteoblastic activity and bone apposition was found on the periosteal surface towards which the teeth

were being moved, and on the surfaces of the alveolus away from which the teeth were moving. An interesting finding from this study was that new bone formation was more pronounced at the intermediate and apical levels.

Verna et al. (1999) was an improvement on the previous study design in that the sample size was larger, the contralateral side sans coil spring acted as a control, the coil spring used delivered a constant force for a given range of activation, and, most importantly, that not only was the apposition and deposition of the bone measured, but also the change in osteoblastic activity. However, the limitation of applying the force to only a single tooth verses arch wires that engage all teeth, still applied.

Ogihara et al (2003) and Verna et al (1999) studied the movement of the molars within the envelope of alveolar bone. This begs the question: what are the effects of alveolar bone formation when teeth are forced to undergo excessive facial and buccal positioning?

Engelking et al (1982) studied the effect of maxillary and mandibular incisor repositioning on the hard and soft tissue periodontium. Five adult pigtail monkeys' maxillary and mandibular incisors purposely underwent severe labial displacement through the labial alveolar bone in order to create a bone dehiscence. This extreme facial position was then maintained for five months. After this period of retention, these same incisors were retracted lingually into their original positions and a further four to six months of retention ensued. The animals were sacrificed, and the alveolar bone was histologically evaluated.

CWRU School of Dentistry
Department of Orthodontics
10900 Euclid Avenue
Cleveland, Ohio 44106-4905

Osteogenesis in the periodontium was found resulting in reapposition of labial bone. In fact, approximately 50% of the original decrease in bone was recovered via reapposition. In other words, once these teeth were moved into a more normal environment, the bone regenerated. Regarding the soft tissue, all net changes found were negligible i.e. there was no statistically significant changes in width of keratinized gingiva, gingival recession, or attachment level in these incisors. Even the authors concur that the negligible "effect on the periodontal soft tissues . . .was partly unexpected" (Engelking et al 1982). This was an improvement on the previous two research designs in that soft tissue changes were also documented. Furthermore, the oral hygiene of the animals was maintained by brushing three times a week, which eliminated the potential for inflammation to affect bone apposition.

Thilander et al (1983) did a similar study on six dogs: three of which acted as subjects and three as controls. Orthodontic appliances were placed and, over a period of five months, were used to move the incisors labially intentionally creating alveolar bone dehiscences and fenestrations. Subsequently, over the course of an additional five months, these teeth were returned to their original position. These teeth were then retained in this position an additional five months. They found similar findings to Engelking et al (1982) in that although dehiscences and fenestrations were created by extreme labial movements, once these teeth were repositioned, bone reformed. Furthermore, there was no net loss of connective tissue attachment.

The effect of orthodontic expansion on the periodontal soft tissue is controversial. Watson (1980) reported that the primary risk of arch wire expansion is the thinning of the bone overlying the roots potentially resulting in dehiscence and/ or fenestration. Alveolar dehiscence is results from lowering the crestal bone. Fenestration is the presence of an actual defect or opening in the cortical plate overlying the root surface. The fear is that these dehiscences and fenestrations may result in lengthening of the clinical crowns of teeth and clefting of the gingiva.

Greenbaum and Zachrisson (1982) set out to study the effects of expansion, whether it be skeletal or orthodontic, on the periodontium. They compared the effects of orthodontic treatment verses rapid and slow palatal expansion on the following periodontal parameters of the maxillary first molars: level of marginal bone, attachment levels, probing depths and width of keratinized gingiva. The sample consisted of twenty-eight patients treated with rapid palatal expansion using an acrylic expander, thirty-three with slow expansion using a quad helix, and twenty-eight patients post-orthodontic treatment that were treated with edgewise technique only. All measurements were made with a Michigan probe.

They found no clinically significant difference amongst the three groups in any of the periodontal parameters studied, and no changes were greater than 0.5 mm. Even the authors stated that they found that their "observation was . . . unexpected." These findings were corroborated by Wennstrom et al (1987) and Karring et al (1982) who found that apical displacement of the buccal alveolar crest does not cause migration of the junctional epithelium and loss of connective attachment.

This is especially true in the absence of local gingival inflammation (Artun et al 1988).

It is important to note; however, that the presence of dehiscences and fenestrations are prevalent in the general population and are in no way unique to orthodontically treated patients. Rupprecht et al (2001) looked at a representative sample of 146 American skulls ranging in ages between 17-87 years old and found that a dehiscence on one or more teeth was found in 40% of the skulls, and a fenestration on one or more teeth was present in 60% of the skulls. This study concluded that the alveolar dehiscences and fenestrations in American skulls is a common occurrence. Davies et al (1974) evaluated almost 400 British skulls and found that over half of these skulls had two or more alveolar dehiscences or fenestrations. Kawasaki et al (1977), Urbani et al (1991), and Nimigean et al (2009) have all since corroborated the above with the average percentage of dehiscences and fenestrations in the general population averaging greater than 50%. These percentages may seem high; however, it is important to realize that these percentages are of skulls not percentages of teeth, the latter also being a common way to report these findings.

All previous studies discussed utilized bone staining, histologic sections and/or 2-d radiographs to investigate the effects of orthodontic treatment on the alveolar bone. These techniques predominated in the past, but the advent of 3-d imaging has taken bone studies to a new level. The first computed tomography (CT) scanner was developed by Sir Godfrey Housfield in 1962; however, it was not until

1982 that Timms et al. published the first study using the CT to evaluate the effects of orthodontic treatment, specifically rapid maxillary expansion, on alveolar bone. Since then, numerous studies have used CT scans to assess alveolar bone changes in response to orthodontic treatment.

Garib et al. (2006) studied the periodontal effects of rapid maxillary expansion using CT scans. The sample size consisted of eight girls ranging in age from 11-14 years old. The rapid palatal expander was activated a consistent seven millimeters, and spiral CT scans were taken before expansion and three months after the completion of expansion. Axial sections parallel to the palatal plane were evaluated. Buccal and lingual bone plate thickness was measured at the level of the furcation of the right maxillary first molar.

With regards to the thickness of alveolar bone of supporting teeth, they found a 0.6 to 0.9 mm reduction of the buccal bone plate thickness and a 0.8 to 1.3 mm increase in the lingual bone plate thickness. This study was an improvement on other studies in that the effects on alveolar bone in living human patients in three dimensions of space was possible. However, the CT scan was taken post-expansion and not post-orthodontic treatment, and even the authors concur that a "small sample . . . was used," which may have affected the reliability of their findings.

One of the most recent studies using CT scans to assess the effects of rapid palatal expansion on dental and periodontal changes was executed by Ballanti et al. in 2009. The sample consisted of seventeen patients treatment planned for rapid palatal expansion. A CT scan was taken before rapid palatal expansion, at the end

of active expansion which was consistently 7 mm in every patient, and after a retention period of six months. Similar to the previous study, evaluation of buccal and lingual alveolar bone changes was done on axial slices at the level of the furcation of the maxillary first molar.

With regards to changes in alveolar bone, they found a statistically significant decrease in buccal alveolar bone thickness averaging 0.4 mm, and statistically significant increases in palatal alveolar bone thickness of 0.6 mm. Both of these studies were advantageous in the sense that there was no variability in the amount of expansion; however, Ballanti et al. (2009) improved on the previous study design by taking the CT scan after a longer period of retention, allowing for more bone repair and reossification. Although the sample size was larger than the previous study by Garib et al. (2006) it was still relatively small, as once again a CT scan was taken which due to its higher radiation dose, limits the sample size.

Langland et al. (1995) found that computed tomography scans are an accurate diagnostic tool to evaluate alveolar bone while being able to orient the skull in all three dimensions of space. The primary disadvantages of computed tomography scans are that they are expensive, and subject patients to high radiation doses. Garib et al. (2006) even clearly states that the "small sample in th(eir) study was justified by ethical considerations, which limit radiation exposure for research purposes," and that "the ethics committee approved (their) project only because CT scanning can provide...information not obtainable from other methods..." With the advent of cone beam computed tomography (CBCT), this is no longer the case.

The same year, 1982, that Timms et al. published the first study utilizing the CT to evaluate alveolar bone changes in response to orthodontic treatment, the first CBCT scanner ever to be built was assembled in the Mayo clinic and designated to be used for angiography. The use of CBCT since then has expanded, and it is now used in dentistry. The recent advent of CBCT provides a diagnostic tool equally effective as CT, yet is more financially feasible and boasts radiation doses comparable to a full mouth periapical series (Mah et al. 2003). This has led to an outflow of research utilizing this new technology.

One of the first in vivo studies to determine the accuracy and reliability of CBCT for measuring bone morphology was performed by Leung et al. in 2010. More specifically, they studied the accuracy of CBCT scans as it relates to measuring alveolar bone height and detecting bony dehiscences and fenestrations. Thirteen dry human skulls containing a total of 334 teeth were scanned. The following measurements were recorded directly from the skulls using a digital caliper, as well as indirectly via use of the CBCT scan: from cusp tip or incisal edge to the CEJ and from cusp tip or incisal edge to the bony margin along the long axis of the tooth. Additionally, they evaluated the accuracy of the CBCT in detecting the presence or absence of dehiscences and fenestrations.

They found a statistically significant difference between the direct measurements and those from the CBCT scan. The CBCT scan measurements deviated from the direct measurements by an average of 0.4 mm for measurements to the CEJ, and 0.6 mm for measurements to the bone margin. Regarding the

presence or absence of dehiscences and fenestrations, the CBCT detected the former less often, and the latter three times as often when compared with direct visualization. The authors concluded that the CBCT was more accurate in detecting fenestrations than dehiscences, and was accurate in detecting alveolar bone height in the range of 0.6 mm.

The main limitation of this study was discussed by the authors themselves; dry skulls were used and since the presence of soft tissue alters the final image, this may not be representative of CBCT scans taken on live patients. Furthermore, although there was a statistically significant difference between the direct caliper measurements and the CBCT image measurements, the range of difference is not necessarily clinically significant.

Baumgaertel et al. (2009) in a similar study design utilizing thirty skulls made ten measurements directly from the casts using a digital caliper, and the same ten measurements were repeated using the CBCT images: overjet, overbite, maxillary and mandibular intermolar and intercanine widths, and maxillary and mandibular arch length available and required. They found that the CBCT measurements, when compared to the direct caliper measurements were highly reliable and accurate in the single measurements, and there was no statistically significant difference for single measures. However, in the compounded measures, mandibular and maxillary arch length available and required, the CBCT underestimated the anatomic truth.

Utilizing cone beam computed tomography, Rungcharassaeng et al. (2007) assessed buccal bone changes of maxillary posterior teeth after rapid palatal expansion, and the factors that may affect these bone changes. Thirty consecutively treated patients treatment planned for rapid palatal expansion were selected and two CBCT images were taken: before RPE and three months after the completion of expansion. The CBCT images were analyzed and measurements of buccal bone thickness, bone in the horizontal dimension, and buccal marginal bone levels, bone in the vertical dimension, of posterior teeth were taken.

They found that there was a statistically significant reduction in both parameters after rapid palatal expansion. In fact, for the maxillary first molar, there was a significant correlation between the reduction in buccal marginal bone levels and the amount of expansion. They also found that the thinner the initial buccal bone thickness, the more was the reduction in buccal bone thickness. Limitations to this study included the fact that the "final" CBCT was taken within three months post expansion with the RPE still in place and not at the end of treatment. Even the authors state that others have found evidence of bone formation after longer periods of retention, and state that a "(f)ollow up study is warranted" to evaluate the bone post-orthodontically (Rungcharassaeng et al. 2007) Furthermore, all measurements were made in the coronal slices, and although vertical bone changes are more visible in this dimension, horizontal bone changes are not and perhaps axial slices, as have been used previously in numerous studies, could have been used instead. Even in

the CBCT images accompanying the published article, the buccal bone thickness was unclear.

This last decade has ushered in the more widespread use of the CBCT in dentistry, and as seen above, numerous studies have used this new tool to assess alveolar bone changes after orthopedic expansion. Studies have also been done to assess bone changes after orthodontic expansion, but these studies have utilized histologic assessment via light microscopy, staining, or 2d radiographs of sectioned bone in animals. Using a 2d image to assess alveolar bone thickness changes in living patients is virtually impossible due to the superimposition of dental and bone structures in multiple planes of space (Lang et al 1977).

An exhaustive review of the current literature reveals that no study to date has combined this topic, orthodontic expansion, with this tool, cone beam computed tomography. No published study has been done to date to document alveolar bone changes in response to orthodontic expansion using cone beam computed tomography, and this is the gap in knowledge we hope to address.

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STATEMENT OF THESIS:

The objective of this study is to investigate the effect of orthodontic arch wire expansion on the alveolar bone thickness of the maxillary first molar roots.

Null Hypothesis:

There is no difference in the buccal alveolar bone thickness of the maxillary first molar before and after orthodontic arch wire expansion.

Alternative hypotheses:

There is a difference in the buccal alveolar bone thickness of the maxillary first molar before and after orthodontic arch wire expansion.

Buccal bone thickness of maxillary first molars
before and after orthodontic archwire expansion.

Authors:

1. Randa Zarka D.D.S.[1]
2. J. Martin Palomo D.D.S., M.S.D.[2]
3. Sebastian Baumgaertel, D.M.D., M.S.D.[3]
4. Leena Palomo, D.D.S., M.S.D.[4]
5. Mark G. Hans D.D.S., M.S.D.[5]

1. Resident, Department of Orthodontics, School of Dental Medicine, Case Western Reserve University, Cleveland, OH.
2. Associate Professor and Program Director, Department of Orthodontics, School of Dental Medicine, Case Western Reserve University, Cleveland, OH.
3. Associate Clinical Professor, Department of Orthodontics, School of Dental Medicine, Case Western Reserve University, Cleveland, OH.
4. Assistant Professor and Predoctoral Program Director, Department of Periodontics, School of Dental Medicine, Case Western Reserve University, Cleveland, OH.
5. Professor and Chairman, Department of Orthodontics, School of Dental Medicine, Case Western Reserve University, Cleveland, OH.

Corresponding Author:

Mark G. Hans D.D.S., M.S.D.
Case Western Reserve University
School of Dental Medicine
Department of Orthodontics
2123 Abington Rd
Cleveland, OH 44106

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MANUSCRIPT DRAFT

Title: Maxillary alveolar bone thickness before and after orthodontic expansion.

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Keywords: Cone beam computed tomography, CBCT, alveolar bone thickness, arch wire expansion, orthodontic expansion, dental expansion, maxillary intermolar width.

INTRODUCTION: When orthodontists expand intermolar width is there a decrease in buccal bone support or does this buccal tooth movement induce bone formation? The aim of this study was to detect the effects of modest amounts of orthodontic arch wire expansion on buccal alveolar bone thickness covering the mesial and distal roots of the maxillary first molars. METHODS: Sixty patients treated with a full course of edgewise pre-torqued pre-angulated brackets were evaluated. The expansion group (n=30) consisted of patients who had ≥2mm increase in intermolar width (range = 2.0-3.9 mm). This group was matched on sex, age, and treatment time to patients who had <2mm increase in intermolar width; the non-expansion group (n=30). Pre and post-treatment intermolar widths and alveolar bone thickness of the maxillary first molar roots were measured using a commercially available software program: (OnDemand3D, CyberMed, Seoul, Korea). RESULTS: Before treatment the expansion group had a mean mesiobuccal bone thickness of 1.68±0.6 mm and distobuccal bone thickness of 2.29±0.6 mm. The non-expansion group had a mean mesiobuccal bone thickness of 1.30±0.5 mm and distobuccal bone thickness of 2.20±0.5 mm. After treatment the mean buccal alveolar bone present on the mesial and distal roots was 1.42±0.5 and 2.26±0.6 for the expansion group and 1.29±0.5 and 2.20±0.5 for the non-expansion group. Only the difference in mesiobuccal bone width in the expansion group was statistically significant ($P \leq 0.05$). CONCLUSIONS: Modest archwire expansion of the first molars (up to 2mm per side) appears to be accompanied by deposition of buccal bone. Distobuccal rotation of the maxillary molars reduces buccal bone support on the mesial buccal root.

INTRODUCTION

Increases in maxillary intermolar width can be achieved via orthodontic arch wire expansion or orthopedic expansion of the maxilla by separation of the midpalatal suture. The decision to do one or the other depends as much on clinician preference as the severity of the problem.[5] The primary indication for orthopedic expansion is a true skeletal maxillary deficiency in the transverse plane of space.[5,6] The indications for orthodontic expansion tend to be less clear, but primarily include those in whom: transverse deficiency is minimal, an increase in arch perimeter is needed, and to establish proper arch form. Those who oppose orthodontic expansion typically cite two disadvantages; the first being the conviction that expanded cases are inherently less stable, the second being that expansion can lead to loss of buccal/facial alveolar bone possibly leading to long-term periodontal complications.[23,49] Orthodontic expansion, also known as dental expansion or arch wire expansion, is achieved solely by engaging arch wires into orthodontic brackets.[6] In contrast to orthopedic aka skeletal expansion, orthodontic expansion results primarily from lateral movement of the maxillary posterior teeth, as arch wires do not usually supply enough force to open the mid-palatal suture.[36,44,45]

Studies have been done in the past to assess the changes in buccal alveolar bone in response to orthodontic expansion. These studies have predominantly utilized either histologic assessment of bone via light microscopy or two

dimensional radiographs. Although effective, histologic studies of sectioned bone after tooth movement are only possible on animals, and two dimensional radiographs of living patients are inadequate to assess bone changes due to the superimposition of structures in multiple planes of space. [59]

The first three-dimensional studies came about as the result of the advent of computed tomography; however due to its high cost and high radiation, its value in orthodontic studies was limited due to ethical considerations.[43] Recent advances in radiology have led to the development of a more economically feasible, lower radiation imaging alternative capable of providing the same information in three dimensions of space: cone beam computed tomography (CBCT). [57,58] Since its introduction, CBCT's have been utilized to evaluate the changes of alveolar bone in response to orthopedic rapid palatal expansion.[26] Yet to date no study has reported on the effect of modest amounts of orthodontic expansion on buccal bone thickness covering the maxillary first molar roots. The present study uses CBCT to address this question.

There are two possible outcomes when maxillary first molar width is increased. First, there could be a resultant decrease in buccal bone support equal to the amount of increase in molar width. In other words, if the intermolar width increases 2 mm (1 mm per side), one would expect buccal bone support to decrease by an equivalent amount (1 mm per side). The second possibility is that tooth movement may trigger buccal bone deposition. If this is the case, when the tooth is moved buccally additional bone is deposited to maintain buccal bone support. The

present study examines the effect of modest amounts of intermolar expansion on buccal bone support of the maxillary first molar.

MATERIALS AND METHODS

This study was approved by the Case Western Reserve University (CWRU) Institutional Review Board. The study sample consisted of all patients in CWRU's Department of Orthodontics who had orthodontic treatment initiated by September 2005 and completed by December 2009, and had pre-treatment and post-treatment CBCT images and dental plaster models available. A total of 426 patients met these inclusion criteria and maxillary intermolar width was measured on the study casts to identify the final study sample. All patients who had ≥2 mm of maxillary expansion were recorded: 98 patients. Of these 98 patients, 68 were excluded due to having had maxillary extractions, rapid palatal expansion, and/or a maxillary appliance that might have increased intermolar width (such as high pull headgear, or a molar distalizing appliance). This resulted in a final sample size of thirty patients who met the inclusion and exclusion criteria listed below.

Setting alpha error at 0.05 and beta error at 0.20, a sample size calculation using a mean effect size of 0.5mm and a standard deviation of 1mm indicated that a minimum sample of 25 patients was needed for this study. Although sample size calculations indicated that a minimum sample of 25 patients was needed for this study, all eligible subjects who met the inclusion and exclusion criteria were included.

CWRU School of Dentistry
Department of Orthodontics
10900 Euclid Avenue
Cleveland, Ohio 44106-4905

Inclusion criteria

Expansion Group: patients who had ≥2 mm increase in maxillary intermolar width.

Non-Expansion Group: patients who had <2 mm increase in maxillary intermolar width

For both Groups: both maxillary first molars present and erupted and pre-treatment and post-treatment dental plaster models and CBCT scans available.

Exclusion criteria (the same criteria were applied to both groups):

Patients who had rapid palatal expansion, any maxillary appliance, any maxillary permanent teeth extracted or congenitally missing (not including third molars), a previous history of orthodontic treatment including early treatment, supernumerary maxillary teeth. previous endodontic treatment on maxillary first molars, surgery to the head and neck, and/or craniofacial syndromes and/or anomalies.

All CBCT scans were taken in the Craniofacial Imaging Center at CWRU using a field of view large enough to capture the craniofacial complex (CB MercuRay™, Hitachi Medical Systems America Co. – Twinsburg, OH). The lowest millamperage setting of 2mA was used. These settings resulted in a voxel size of 0.38mm.

The expansion group consisted of 30 adolescents (17 male and 13 female) with an average start age of 13.4 years (standard deviation: 1.3, range: 11.5 - 15.5 years) and mean treatment time of 23.8 months (range: 19.0 – 28.0 months). These

patients were matched individually according to age, gender, and treatment time to patients in the non-expansion group that met the same inclusion and exclusion criteria. The non-expansion group consisted of 30 adolescents (17 male and 13 female) of an average start age of 13.4 years (range: 11.5 - 15.7 years), and a mean total treatment time of 25.0 months (range: 23.0 – 28.0 months). All data were collected, masked and subsequently measured by a single operator (R.Z.). Two sources of data were utilized for measurements: dental plaster models and CBCT scans.

Pre-treatment and post-treatment dental plaster models of patients in both groups were used to measure intermolar width before and after orthodontic treatment using a Mitutoyo digimatic caliper calibrated to the nearest 0.01 mm (model no. 500-196-20, Mitutoyo American, Plymouth, Michigan) and directly inputted into Excel 2007 (Microsoft, Redmond, Wash). Intermolar width was measured from the deepest portion of the central fosses of contralateral maxillary first molars in accordance to not only numerous previous studies,[26,46-48] but also this is the point from which Graber et al.[39] measures transverse changes in his transverse envelope of discrepancy.

Pre-treatment and post-treatment CBCT scans of patients in both groups were used to construct radiographic images which were stored as a jpeg images, and analyzed using OnDemand3D software (CyberMed, Seoul, Korea). Using this software, the sagittal, coronal, and axial planes were set as described below.

1. In the sagittal view, the axial plane was set parallel to the palatal plane denoted by a line bisecting the anterior nasal spine (ANS) and the posterior nasal spine (PNS). See figure 1.
2. In the coronal view, the axial plane was set parallel to the inferior border of the zygomatic arches. See figure 2.
3. In the axial view, the sagittal plane was set to bisect ANS and PNS. See figure 3.

The axial view was then expanded. All measurements of alveolar bone thickness were measured on the axial view at the level of the pulpal furcation of the maxillary right (#3) and left (#14) first molars. See figure 4. The alveolar bone thickness was measured from a perpendicular line drawn from the height of contour of each of the mesiobuccal and distobuccal roots to the buccal limit of the alveolar bone, and from the height of contour of the palatal roots to the palatal limit of alveolar bone. This alveolar bone thickness at the mesiobuccal, distobuccal and palatal roots were measured on the right and left maxillary first molars of each patient, pre and post treatment. The intermolar widths in the axial slice at the level of the pulpal furcation between contralateral mesiobuccal, distobuccal and palatal roots were also recorded. See Figure 5.

A total of 1200 measurements were made on initial and final CBCT images, and 400 were repeated approximately three weeks later on 20 randomly selected patients to assess intra-operator reliability. All original and repeated measurements were made by a single operator (R.Z).

STATISTICAL ANALYSIS

Statistical analysis was performed using the Statistical Package for the Social Sciences software (version 17.0.1; SPSS, Inc., Chicago Ill). Paired t-tests were used to compare the significance of the differences between and within the two groups ($P \leq 0.05$). No tests were performed to compare the effects of independent variables (such as bracket system, race, etc) since our sample size for these subgroups was too small to yield meaningful results. Intraclass correlation coefficients (r) were calculated to estimate the reliability of the method. Means, standard deviations and ranges were collected and calculated for all initial and final measurements taken both on the CBCT scans and dental plaster cast models using Excel 2007 (Microsoft, Redmond, Wash).

RESULTS

The intraclass correlation coefficient between repeated measures ranged between 0.86 and 0.99, well within the range of acceptability.

Paired t-tests comparing the right maxillary first molar to the left maxillary first molar revealed no statistically significant difference between the two sides, and therefore the data were pooled for subsequent analysis.

There was a statistically significant difference between the pre-treatment mean intermolar widths of the two groups: expansion group 40.91±4.97 mm and non-expansion group 44.16±3.11 mm ($P \leq 0.05$). The post-treatment (T2) intermolar width measurements for the two groups was not significantly different: expansion

group 43.78±4.67 mm, and non-expansion group 44.48±3.25 mm ($P \leq 0.05$). There was a statistically significant difference in the change in intermolar width between the expansion group and non-expansion groups: 2.87±0.58, and 0.33±0.94 respectively ($P \leq 0.05$), consistent with the use of this variable to define the expansion and non-expansion groups. The results from the inter-molar widths measured from the CBCT images at the level of the furcation of the maxillary first molars, were, as expected, consistent with those from the dental plaster models. Namely, a statistically significant increase in intermolar widths in the expansion group, no statistically significant increase in the interradicular intermolar widths in the non-expansion group, a statistically significant difference in intermolar widths between the groups pre-treatment, and no statistically significant difference between the groups at the end of treatment. Neither group had a statistically significant difference in intermolar width when measured at the apex of the palatal root.

Regarding alveolar bone thickness, pre-treatment, the mesiobuccal alveolar bone thickness in the expansion group was greater than that in the non-expansion group by and average of 0.38 mm ($P \leq 0.05$). Post-treatment, although there was a decrease (0.26 mm) in mesiobuccal alveolar bone thickness in the expansion group ($P \leq 0.05$), when comparing the two groups there was no statistically significant difference in the mesiobuccal alveolar bone thickness between the expansion and non-expansion groups. Regarding the distobuccal alveolar bone thickness, there was no statistically significant difference or change between or within the two groups pre-treatment (expansion: 2.29±0.6, non-expansion 2.20±0.5) or post-treatment

(expansion: 2.26±0.6, non-expansion 2.20±0.5). See Table 2 for means and standard deviations for all variables.

DISCUSSION

With the recent advent of CBCT technology, with its relatively low radiation, low cost, and reasonable ubiquity, evaluation of hard tissue changes in all three dimensions of space is now possible.[40,41] The accuracy of using CBCT images to make linear measurements, similar to the ones used in our study, has been verified, as has its accuracy in evaluating changes in alveolar.[34,54] Recent years have witnessed an onslaught of published literature using the CBCT to evaluate changes undergone during orthodontic treatment, and with this a cacophony of methods developed to best orient and analyze these CBCT images. The method used here to assess the changes in alveolar bone thickness utilizes axial sections oriented parallel to the palatal plane at the level of the furcation of the maxillary first molar. This method was first published by Garib et al.[43] in 2009, and subsequently utilized by Paulus et al. in 2010.[42] This method is sound, not only in its high reproducibility as indicated by our and their high levels of intraclass correlation, but also in that it evaluates for alveolar bone changes in an area in which they are most likely to occur: the maxillary first molar.

We chose to measure bone support at the furcation level because changes in alveolar bone thickness in response to expansion are most likely to occur at this

level since it has been shown that the highest forces in orthodontics are applied at the root-alveolar crest junction and not at the root apex as one may suspect.[28-30,32]

Also, the maxillary first molar, of all the posterior teeth, exhibits the greatest change in alveolar bone thickness in response to orthopedic expansion, and one can extrapolate that the same would apply for orthodontic expansion.[43] Furthermore, studies have shown that the maxillary first molar has one of the highest incidences of dehiscences and fenestrations in the oral cavity. [12,50] In other words, if there is going to be a deleterious effect from arch wire expansion on the alveolar bone thickness in the oral cavity, one would expect it to most likely to occur in the alveolar bone at the level of the furcation of the maxillary first molar.

Our study examined cases with modest amounts of archwire expansion up to 2mm per side. This upper limit of expansion was chosen somewhat arbitrarily. Pre and post treatment intermolar width was measured on all dental plaster models for all patients debonded by 2009. The 30 cases with the greatest increase in intermolar width were selected for this study. This suggests that orthodontists (represented by the twenty one instructors in our clinic who treated these patients) likely employ rapid palatal expansion in cases that require more than 2 mm of increase in inter molar width. This amount of archwire expansion is consistent with Graber's concept of the transverse envelope of discrepancy.[39] According to Graber, the limit of orthodontic tooth movement in the maxilla in the transverse dimension of space is 2mm.[39] In other words, changes of greater than 2mm require orthopedic or surgical intervention. This is an important limitation of this study as we did not examine the

effects of large amounts of archwire expansion on buccal bone support. It is not likely that the inductive effect of lateral tooth movement on buccal bone depository activity extends indefinitely as has been suggested by some clinicians.

It is interesting to note that more males underwent arch wire expansion. Longitudinal studies have found that male arches become wider than female arches from birth to twenty-five years.[14] Therefore, the net amount of increase in arch width that we measured may have been a combination of increase due to the orthodontic treatment and a natural increase with age. Secondly, males, as later maturers, continue to grow more than their female counterparts in the transverse dimension of space.

With regards to changes in alveolar bone thickness, there was a statistically significant decrease at the mesiobuccal root in the expansion group post-orthodontic treatment. Although an initially alarming finding, this warrants further evaluation. Firstly, this statistically significant decrease was on average 0.26 mm, an amount most would concur is not clinically significant. Secondly, there was a statistically significant difference between the expansion and non-expansion groups pretreatment, with the former exhibiting 0.38 mm *greater* buccal alveolar bone thickness. Thirdly and most importantly, at the end of treatment, there was no statistically significant difference in mean alveolar buccal bone thickness between the expansion (1.42 mm) and non-expansion groups (1.29). In actuality, even though there was a statistically significant *decrease* in buccal alveolar bone thickness measured at the mesiobuccal root as a result of orthodontic treatment, the

average post-treatment bone thickness was actually greater in the expansion group by an average of 0.13 mm, and although this amount was not statistically or clinically significant, its presence is worth noting.

Palatal bone thickness was measured but we found no significant findings or changes in this parameter. Bone coverage on the palatal root is typically not a concern for orthodontists due to its thickness. It has been repeatedly reported that the vast majority of deleterious alveolar bone defects such as dehiscences and fenestrations, occur only in the buccal bone.[19-22]

The location of the only statistically significant changes in bone thickness in our study was at the mesiobuccal root. Possible explanations for this include the fact that the mesiobuccal root of the maxillary first molar is the most prominent root of the posterior teeth.[43] Prominent roots have been found to have to thinner overlying bone, and root prominence predisposes to buccal bone dehiscences and fenstrations.[51] This is corroborated by the fact that Larato et al.[21] found that 90% of alveolar bone defects occurred in association with prominent roots. Furthermore, dehiscences are most common in the mesiobuccal root of the maxillary first molar. [56] Even in the absence of orthodontic treatment, this preexisting root prominence is a predisposing factor. This may be further exacerbated by orthodontic treatment as a common presenting factor in malocclusions, specifically class II malocclusions, is the mesiolingual rotation of the maxillary first molars.[16,38] To correct this, orthodontic mechanics designed to produce distolingual rotation of the maxillary first molars is routinely employed. Fourteen of the thirty patients in the expansion

group started with a class II malocclusion. Derotation of the molar during this class II correction naturally results in movement of the already prominent mesiobuccal root even further buccally in a distobuccal rotation. The patient in our study who exhibited the greatest amount of bone loss around the mesiobuccal root, also had the most clinically evident rotation of the maxillary first molars. Clinicians should keep in mind the potentially deleterious effects of combining large amounts of archwire expansion with distobuccal rotation of the maxillary first molars.

As with all studies, there are always limitations to any study. Had a larger sample been available, the effect of independent variables such as age, sex, bracket type and so forth could have been evaluated. Furthermore, as our sample size was limited to adolescent patients, our findings may not be applicable to non-growing patients. Had periodontal parameters been recorded in both the expansion and non-expansion groups' pre and post orthodontic treatment, they could have been used to evaluate the effects of local factors such as inflammation or the presence or absence of preexisting periodontal conditions on alveolar bone changes. Also, an analysis of post-retention CBCT images would help elucidate what changes in alveolar bone thickness may occur over time when the bone is given time for regeneration and reossification. Two possible limitations arise from the use of the CBCT scans, which are applicable to any study using CBCT images. Firstly, the accuracy of OnDemand 3D software analyzing an image from Hitachi CB MercuRay CT, is only accurate to ± 0.6 mm.[???] Furthermore, as Leung et al.[34] found, in corroboration with the findings of Haaga et al.[37] who also found: the loss in low contrast resolution in

the CBCT image makes distinguishing between cementum and bone difficult due to their similar densities.

It is important to reiterate that the sample chosen in our study was chosen simply on the basis of the amount of expansion achieved at the level of the crown of the maxillary first molar. They were not patients whose treatment plans specifically included arch wire expansion, they were not patients treated with a specific kind of bracket, they were not patients diagnosed with dental constriction of the maxillary arch. This makes these findings all the more relevant as it seems that the torque built into the bracket delivers a consistent amount of expansion that corrects for the original palatal inclination of the molars if it exits. The torque in the molar brackets used in all patients included in this study, both of the expansion and non-expansion groups, ranged between 20-28 degrees. It is important to mention that the vast majority of arch wires utilized in the treated patients were square and ovoid preformed arch wires

Ultimately, orthopedic expansion is an essential treatment tool in the alleviation of true skeletal crossbites. Dental expansion also has a role in orthodontics in alleviating mild transverse deficiencies and establishing a proper arch form. It is up to the clinician to decide if moderate orthodontic expansion is stable. Our results, however, do suggest that, in the range of arch wire expansion evaluated here, concerns over loss of buccal bone support do not seem to be justified.

CONCLUSION

Although archwire expansion does result in a statistically significant decrease in buccal alveolar bone thickness on the mesiobuccal root, the resultant decrease of 0.26 mm is not clinically significant, and post-treatment both groups had no statistically significant difference in final alveolar bone thicknesses. In other words, although there was a net change, there was no net difference. Therefore, within the parameters of expansion evaluated in this study, in the range of 2-3.9 mm, expansion appears to have no net deleterious effects on the buccal alveolar bone.

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CWRU School of Dentistry
Department of Orthodontics
10900 Euclid Avenue
Cleveland, Ohio 44106-4905

Table 1.-- Summary demographics and treatment information for expansion[a] and non-expansion[b] groups

	Expansion group[a] (mean ± SD)	Non-expansion group[b] (mean ± SD)
Age at start (y):	13.4 ± 1.3	13.4 ± 1.3
Treatment time (mos):	24 ± 2.4	25 ± 1.3
Gender Male:	17	17
Female:	13	13

a: ≥2 mm increase in intermolar width

b: <2 mm increase in intermolar width

Table 2.-- Comparison of pre-treatment (time 1) and post-treatment (time 2) measurements using paired T-tests [a,b]

	Expansion Group (E)		Non Expansion Group (NE)	
(mm)	Time 1	Time 2	Time 1	Time 2
Dental Cast Intermolar Width	40.9±4.9[+]	43.8±4.7*	44.2±3.1[+]	44.4±3.2
Interapical molar Width	33.3±3.1	33.2±3.3	32.3±2.7	32.3±2.6
Mesiobuccal alveolar bone thickness	1.68±0.6*,[+]	1.42±0.5*	1.30±0.5[+]	1.29±0.5
Distobuccal alveolar bone thickness	2.29±0.6	2.26±0.6	2.20±0.5	2.20±0.5
Palatal alveolar bone thickness	1.23±0.4	1.33±0.5	1.15±0.5	1.21±0.5

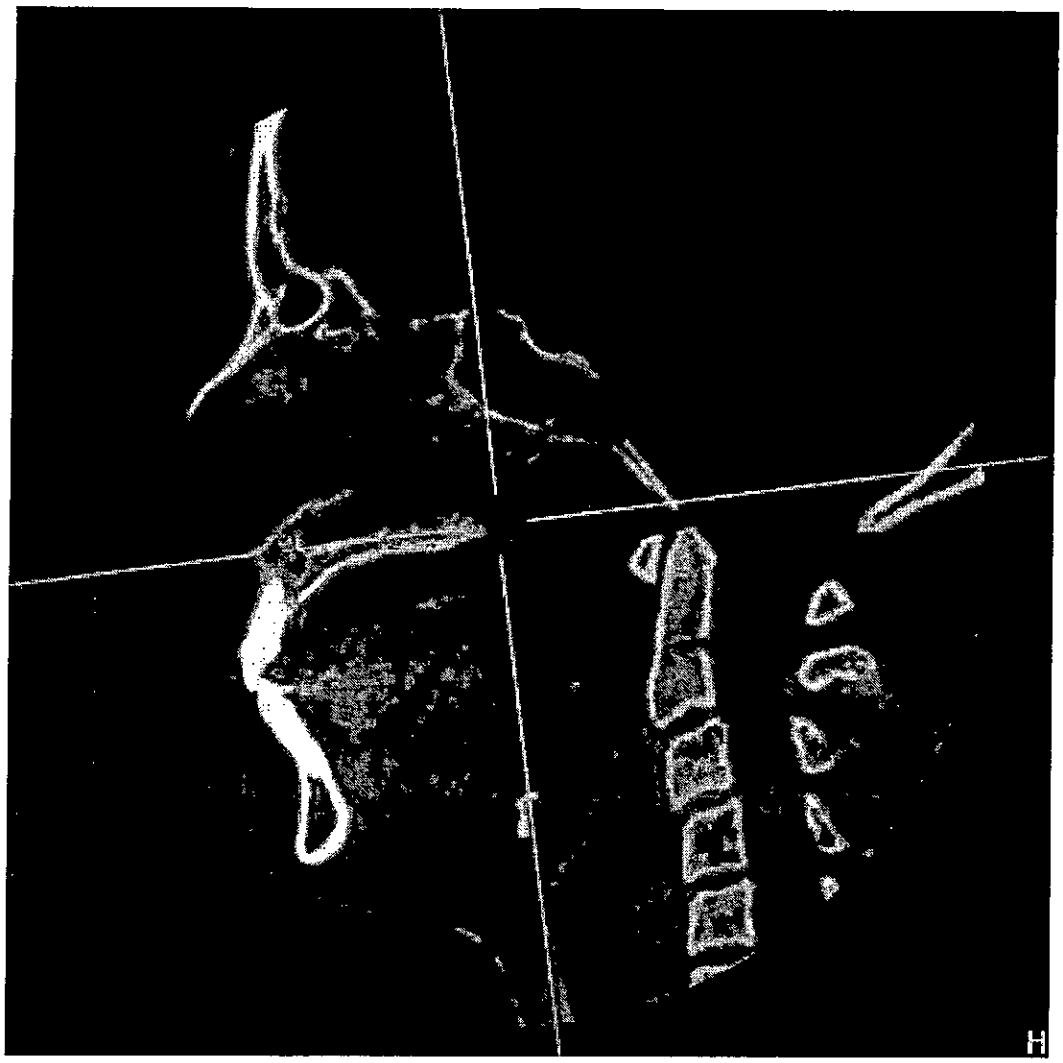
a All alveolar bone measurements are an average of the maxillary right and left first molars.

b Intraexaminer reliability (r)>0.9 for all measurements

* *Statistically significant change from Time 1 to Time 2 ($P \leq 0.05$)*

[+] *Statistically significant difference between groups ($P \leq 0.05$)*

Figure 1.-- CBCT image in the sagittal view, setting the axial plane.



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10900 Euclid Avenue
Cleveland, Ohio 44106-4905

Figure 2.-- CBCT image in the coronal view, setting the axial plane.

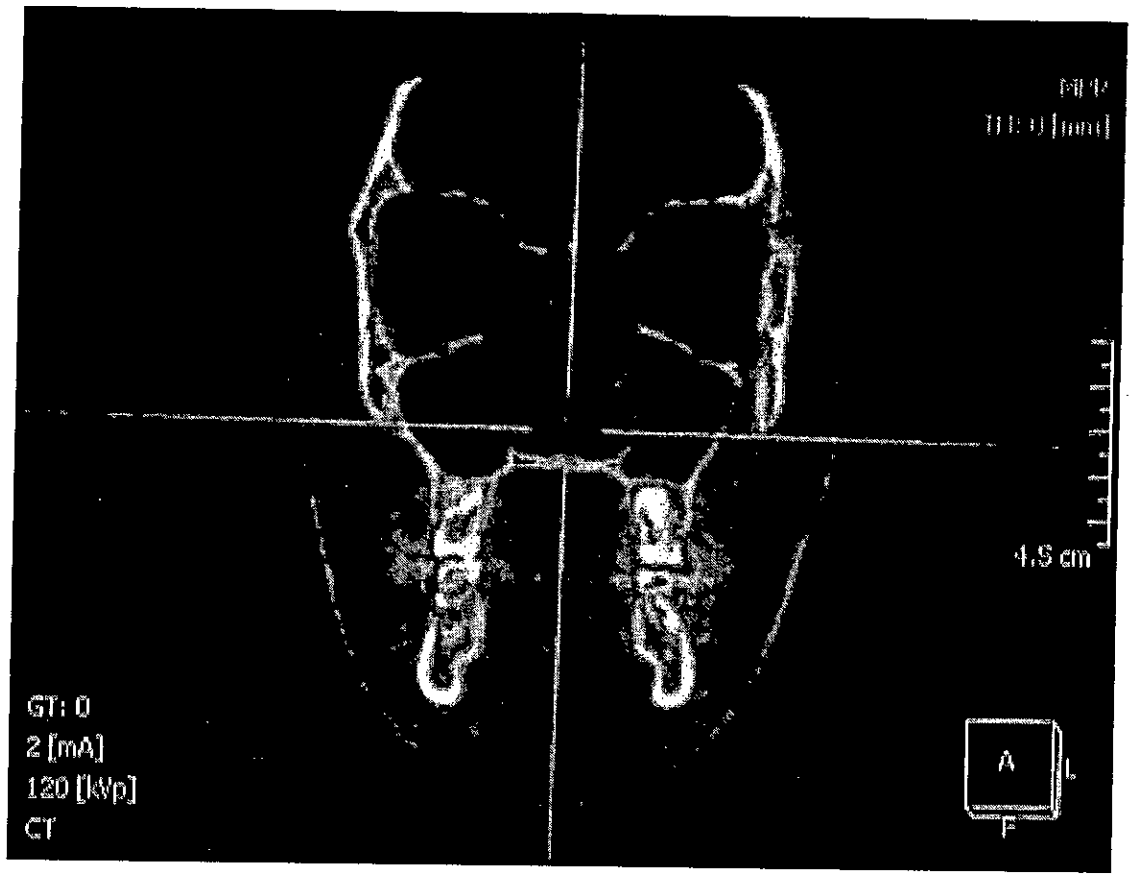


Figure 3.—CBCT image in the axial view, setting the sagittal plane.

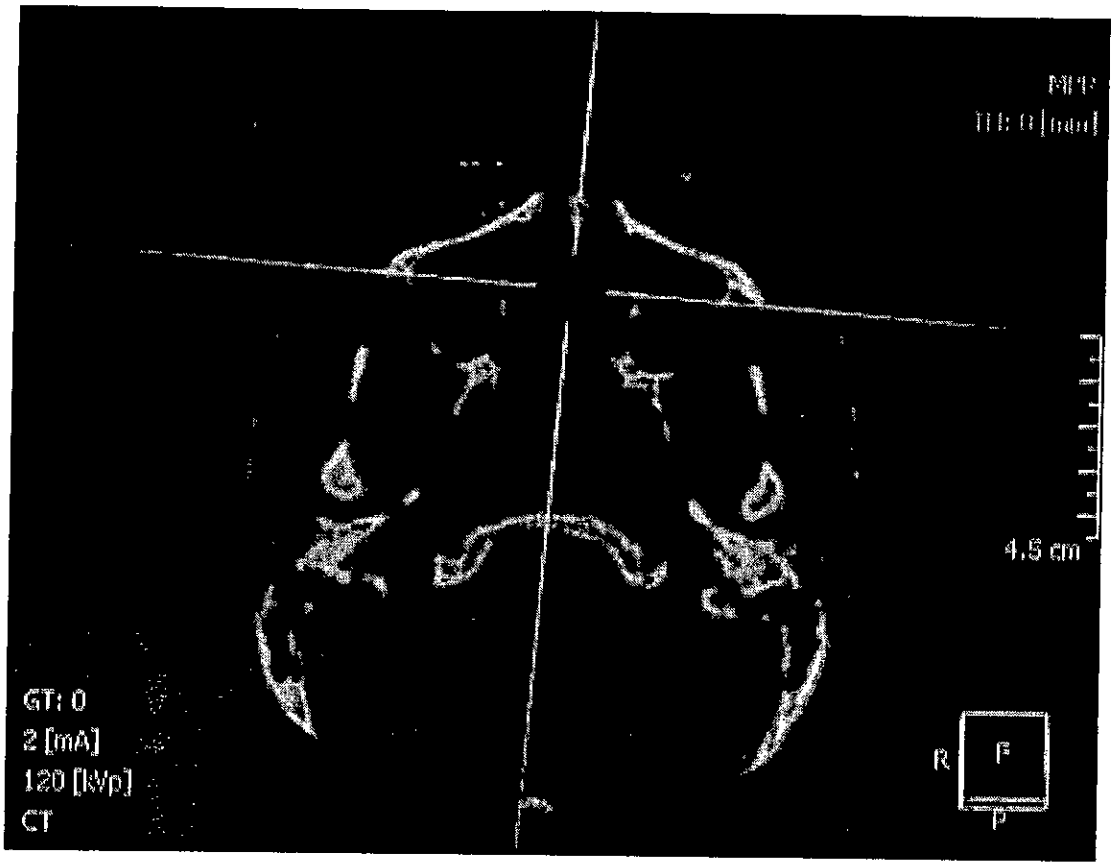


Figure 4.-- Axial view at the level of the pulpal furcation.
Meauring buccal and palatal alveolar bone thickness of tooth #3 and #14.

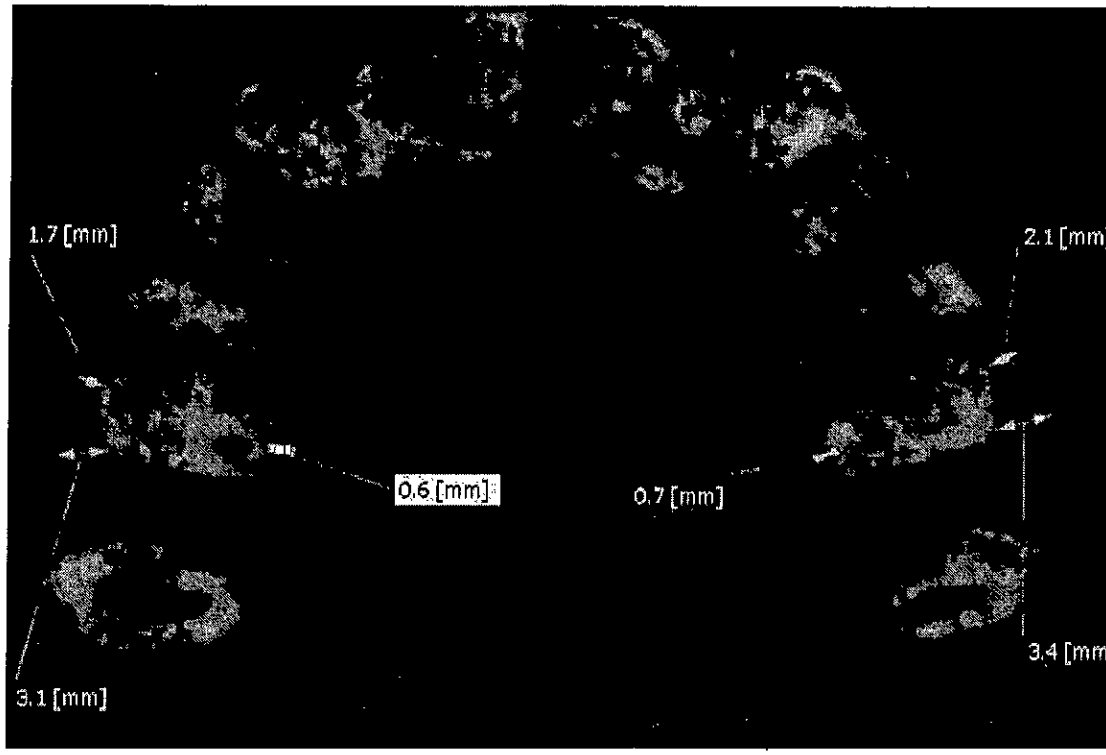
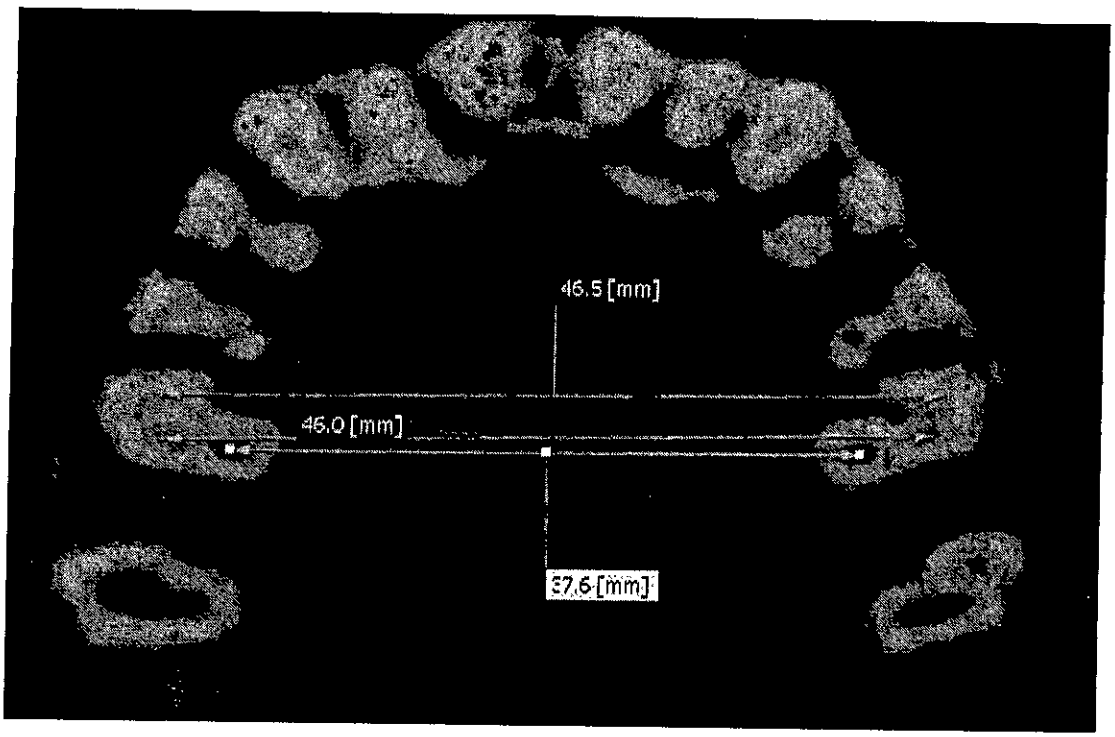


Figure 5.-- Axial view at the level of the pulpal furcation.
Measuring the mesiobuccal, distobuccal and palatal intermolar widths between #3-14.



APPENDIX 1: IRB APPROVAL

Case Western Reserve University Institutional Review Board

NOTICE OF EXEMPTION (#4)

Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior

Exemption Date: February 17, 2010

The Institutional Review Board (IRB) has deemed the above protocol EXEMPT under 45 Code of Federal Regulations (CFR) part 46.101(b)(4). The IRB will not conduct subsequent reviews of this protocol.

Any changes to the protocol that put it under the purview of the IRB would require a formal application to, and approval of, the IRB prior to implementation of the change IRB applications are available at the CWRU IRB Pages, or from the Office of Research Compliance (ORC) at Sears Library Building, #657.

Responsible Investigator: Mark Hans
Department: Dental Orthodontics
IRB Protocol Number: 20100204
Title: Case Control Study of Bone Thickness Buccal and Lingual to the Maxillary First Molar Roots Before and After Orthodontic Treatment
Co-Investigator: Randa Zarka

Appendix 2: List of individual expansion patients' general information

Patient	Male/Female	Birthday	Start Age (yrs)	Finish Age (yrs)	Tx Time (mos)
JO187	F	03/25/1995	11.48	13.61	25
JU19	M	03/19/1995	11.48	13.38	22
MI171	M	12/18/1995	11.57	13.91	28
CA202	F	09/29/1995	11.62	13.86	27
CO207	F	12/15/1994	11.86	13.48	20
IS24	F	08/27/1995	12.14	14.06	23
MA281	M	09/01/1994	12.16	14.19	25
SY7	F	05/31/1995	12.31	14.25	23
BE158	F	07/10/1995	12.32	14.08	21
HO178	M	03/08/1994	12.35	14.64	27
TO41	M	05/04/1994	12.54	14.33	21
VI21	F	02/08/1995	12.67	14.78	25
BA182	F	11/18/1993	12.73	14.33	19
AN56	F	08/12/1994	12.94	14.94	24
GR123	M	04/23/1993	13.23	15.28	24
HU66	M	06/09/1993	13.37	15.38	24
KO83	M	11/20/1993	13.78	15.97	27
LI69	M	08/14/1993	13.93	16.23	28
RO181	F	10/31/1992	14.12	15.97	22
GO103	M	07/27/1992	14.20	16.29	25
LE125	F	07/29/1993	14.30	16.03	21
JE8	M	07/07/1993	14.32	16.30	24
MI159	M	08/03/1992	14.33	16.30	24
TO65	M	03/02/1993	14.65	16.70	25
LE128	M	11/1/1992	14.79	16.92	25
BA186	M	10/17/1991	15.05	17.12	24
SH128	M	09/07/1992	15.12	16.77	20
PO99	F	08/01/1992	15.14	16.99	22
FL43	F	07/15/1991	15.16	17.36	26
SI56	M	04/13/1992	15.54	17.49	24

Appendix 3: List of individual non-expansion patients' general information

Patient ID	Male/ Female	Birthday	StartAge	Finish Age (yrs)	TxTime (mos)
SC142	F	6/13/1996	11.48	13.44	23
HA340	M	1/24/1996	11.69	13.79	25
BI60	M	12/10/1995	11.82	13.43	25
KO107	F	3/4/1996	11.72	13.68	24
CO237	F	2/8/1996	11.77	13.78	24
BE161	F	10/11/1995	12.10	13.88	24
IS22	M	7/18/1995	12.19	14.33	26
HE106	F	7/2/1995	12.38	13.95	24
PA148	F	8/24/1995	12.16	14.13	25
JO97	M	12/28/1994	12.73	14.80	26
MU83	M	3/13/1995	12.66	14.67	24
EV17	F	11/29/1994	12.72	14.65	23
BA175	F	3/30/1994	13.34	15.45	25
HA295	F	9/18/1994	13.08	15.06	24
PE149	M	4/29/1994	13.30	15.45	27
SC151	M	4/24/1994	13.32	15.12	27
KO82	M	11/20/1993	13.78	15.97	27
DI88	M	7/24/1993	13.97	15.89	28
GE41	F	9/18/1993	14.15	15.91	24
PE151	M	6/10/1993	14.36	16.38	25
BO165	M	4/24/1993	14.28	16.37	27
CI27	F	3/23/1993	14.64	16.59	24
LO61	M	1/8/1993	14.73	16.84	26
NE74	M	5/1/1993	14.47	16.42	25
BR135	M	3/2/1993	14.73	16.69	24
WI241	M	11/11/1992	15.03	16.53	24
MA329	M	4/16/1993	14.62	16.56	24
MC156	F	10/8/1992	15.04	16.39	25
RE110	F	2/27/1992	15.70	17.64	24
ZU16	M	9/7/1992	14.98	17.12	27

Appendix 4: Expansion patients' initial intermolar widths and alveolar bone widths before orthodontic treatment (mm)

Patient ID	Palatal Root Intermolar Width	Mesiobuccal Root Intermolar Width	Distobuccal Root Intermolar Width	Interapical Intermolar Width	Tooth#3 Mesiobuccal Bone Thickness	Tooth#3 Distobuccal Bone Thickness	Tooth#3 Palatal Bone Thickness	Tooth#14 Mesiobuccal Bone Thickness	Tooth#14 Distobuccal Bone Thickness	Tooth#14 Palatal Bone Thickness
JO187	35.5	42.9	42.5	31.9	0.9	2.8	1.0	1.2	2.7	1.3
JU19	40.7	47.7	47.1	32.7	1.7	1.9	1.2	0.8	2.0	1.2
MI171	38.7	48.9	48.4	28.7	1.4	2.0	1.9	1.1	2.2	2.0
CA202	35.3	42.0	41.4	31.1	2.0	2.6	1.0	1.6	2.1	0.8
CO207	34.4	43.6	43.4	31.6	1.5	2.6	1.0	1.7	2.4	1.1
IS24	40.8	50.6	49.8	37.2	2.2	2.5	1.2	2.4	2.8	1.4
MA281	40.0	48.5	47.5	36.6	3.0	2.5	1.3	2.7	2.9	1.9
SY7	33.4	42.3	42.1	27.6	1.6	2.5	1.8	2.1	2.1	1.5
BE158	37.5	46.4	46.6	33.1	2.3	2.9	1.4	2.0	2.6	1.5
HO178	42.1	53.0	51.5	32.9	2.0	3.2	0.6	2.5	3.9	1.2
TO41	37.3	46.0	46.6	28.5	2.5	2.2	1.2	1.6	1.6	0.8
VI21	33.1	43.3	42.5	31.5	1.8	2.5	1.5	1.4	1.6	1.3
BA182	39.6	44.2	45.8	37.2	2.5	2.6	1.1	3.0	2.3	1.2
AN56	40.8	49.1	49.7	37.6	2.1	1.8	1.3	1.6	1.6	2.2
GR123	43.1	49.3	50.2	37.2	1.7	2.3	0.8	1.5	2.7	0.8
HU66	42.4	51.7	51.5	38.0	1.4	1.6	1.4	1.3	1.2	1.6
KO83	37.0	45.8	45.2	29.8	2.0	3.3	0.8	0.9	2.2	0.9
LI69	44.2	54.5	52.3	35.9	2.2	3.3	0.7	2.0	4.0	1.3
RO181	44.0	52.5	52.3	34.8	2.0	1.8	0.9	1.8	1.2	0.9
GO103	37.8	48.9	47.3	31.3	1.6	2.3	0.8	1.6	2.5	1.2
LE125	40.0	46.8	46.9	31.9	1.3	1.5	0.7	1.1	1.6	1.3
JE8	38.5	48.3	48.0	31.7	1.3	2.4	1.6	1.3	2.4	1.7
MI159	39.6	48.3	49.6	33.1	1.3	1.8	0.9	0.7	1.1	1.4
TO65	41.3	51.4	49.7	37.2	1.1	2.1	2.0	1.1	2.0	1.6
LE128	37.2	46.3	45.2	32.3	1.1	1.6	1.0	0.9	1.5	1.0
BA186	41.3	51.6	51.9	36.0	2.8	3.7	1.1	2.1	3.1	1.1
SH128	37.4	46.7	46.1	33.4	2.4	3.1	1.6	1.8	2.0	1.1
PO99	41.3	51.3	51.1	37.2	1.0	2.0	1.1	0.8	1.6	1.1
FL43	35.6	43.0	43.3	29.4	1.2	1.3	1.2	1.3	1.9	1.2
SI56	38.3	48.4	47.9	31.6	1.7	3.0	1.3	1.5	1.8	1.1

Appendix 5: Expansion patients' final intermolar widths and alveolar bone widths after orthodontic treatment (mm):

Patient ID	Palatal Root Intermolar Width	Mesiobuccal Root Intermolar Width	Distobuccal Root Intermolar Width	Interapical Intermolar Width	Tooth#3 Mesiobuccal Bone Thickness	Tooth#3 Distobuccal Bone Thickness	Tooth#3 Palatal Bone Thickness	Tooth#14 Mesiobuccal Bone Thickness	Tooth#14 Distobuccal Bone Thickness	Tooth#14 Palatal Bone Thickness
JO187	39.1	45.9	46.1	35.5	1.6	3.3	1.3	1.4	2.8	0.6
JU19	42.3	49.4	49.7	36.8	1.6	2.0	0.9	1.0	2.1	0.9
MI171	40.8	51.1	51.2	28.7	1.7	2.4	1.4	1.3	2.3	2.0
CA202	37.8	45.5	44.5	33.8	1.4	2.7	1.6	1.1	1.9	1.2
CO207	35.6	45.5	42.6	31.2	1.2	2.3	1.4	1.5	2.5	1.1
IS24	42.2	50.7	50.9	36.0	1.7	2.7	0.9	2.3	2.2	1.2
MA281	40.7	49.7	49.3	36.5	1.8	2.5	1.3	2.3	3.6	1.2
SY7	33.6	44.3	42.5	26.6	1.7	2.4	2.4	1.5	2.4	2.3
BE158	39.4	49.2	48.0	32.2	1.6	2.5	1.4	1.7	2.2	1.2
HO178	42.2	53.1	51.9	33.5	1.7	2.8	1.2	1.8	3.5	1.5
TO41	39.1	49.0	47.6	30.4	1.4	2.8	1.2	1.5	1.6	1.7
VI21	35.2	45.1	43.4	31.6	1.2	2.4	1.3	1.4	2.0	1.8
BA182	40.1	47.4	46.3	37.8	1.2	2.0	1.4	1.6	2.6	1.8
AN56	43.5	50.8	51.1	40.4	1.4	1.7	2.8	0.9	1.2	2.7
GR123	43.5	52.8	52.1	37.2	0.8	2.2	1.7	1.1	2.1	1.9
HU66	41.9	52.6	52.6	38.4	2.0	2.2	2.1	1.3	2.0	1.7
KO83	40.3	50.2	49.5	33.0	1.2	1.8	1.0	1.3	1.7	1.0
LI69	41.7	54.4	53.1	35.0	1.9	2.3	0.8	0.7	3.0	0.8
RO181	43.2	52.4	53.5	35.8	2.0	2.0	0.5	2.0	1.6	1.0
GO103	36.3	49.2	47.2	28.5	1.3	2.9	0.5	1.6	2.4	0.8
LE125	40.1	49.0	48.4	32.6	0.6	1.2	1.4	0.7	1.4	1.6
JE8	37.5	49.8	49.0	29.8	1.8	2.6	1.2	0.6	2.0	1.5
MI159	40.4	50.3	49.8	33.0	1.2	1.6	0.4	1.5	2.6	0.4
TO65	41.4	52.7	50.8	36.8	0.5	1.6	1.2	0.4	1.3	1.6
LE128	37.1	46.9	45.8	30.0	0.6	2.0	0.7	1.3	2.1	1.1
BA186	41.5	50.4	50.1	34.7	2.7	3.4	1.3	2.0	3.3	1.4
SH128	37.1	48.9	47.9	32.2	2.6	1.6	1.4	1.4	2.9	1.4
PO99	42.0	50.8	50.7	35.9	1.1	2.6	1.1	0.7	1.7	1.8
FL43	36.2	44.5	44.2	29.6	1.5	2.1	1.2	1.8	1.7	1.1
SI56	37.5	49.0	47.4	31.0	1.2	1.9	0.7	1.4	2.4	1.0

Appendix 6: Non-expansion patients' initial intermolar widths and alveolar bone widths before orthodontic treatment (mm):

Patient ID	Palatal Root Intermolar Width	Mesiobuccal Root Intermolar Width	Distobuccal Root Intermolar Width	Interapical Intermolar Width	Tooth#3 Mesiobuccal Bone Thickness	Tooth#3 Distobuccal Bone Thickness	Tooth#3 Palatal Bone Thickness	Tooth#14 Mesiobuccal Bone Thickness	Tooth#14 Distobuccal Bone Thickness	Tooth#14 Palatal Bone Thickness
SC142	41.9	47.8	50	34.1	1.6	1.8	2.3	1.6	3.0	2.4
HA340	40.5	50.4	50.3	34.1	1.6	1.4	0.5	1.6	1.2	0.5
BI60	38.1	48	48.8	32.5	1.0	2.0	0.6	0.4	0.4	0.5
KO107	36.8	46.4	46.3	27.8	0.8	2.2	1.0	0.5	2.3	0.9
CO237	39.4	49.9	48.3	33.9	1.5	2.4	0.9	2.0	3.3	1.6
BE161	34.1	42.4	43	30.9	2.1	2.0	1.8	1.3	2.4	1.5
IS22	42.8	51.1	51.3	37	1.9	2.1	1.6	2.2	2.2	1.8
HE106	37.7	45.5	45.7	29.2	2.0	2.2	1.5	2.0	2.4	1.5
PA148	37.4	46.2	46.4	31.7	0.7	1.8	1.2	0.7	2.2	1.3
JO97	37.6	45.3	45.7	30.1	1.3	2.0	1.5	1.7	2.0	1.5
MU83	42.1	52.8	51	34.9	1.1	2.5	1.4	2.7	1.0	1.3
EV17	39.3	48.9	48.4	29.4	2.2	2.6	1.6	2.9	2.3	2.2
BA175	34.1	41.7	41.7	29.3	2.1	2.5	1.7	2.1	2.6	1.6
HA295	38.6	47.4	47.7	29.5	1.3	2.0	1.6	1.7	2.4	1.7
PE149	40.1	49.1	50.9	33.8	1.5	1.9	0.8	1.8	1.8	0.5
SC151	40.6	48.7	47	34.6	2.2	2.3	1.8	2.2	2.7	2.4
KO82	38.1	47.3	46.7	30.5	2.2	3.1	2.0	3.6	3.9	2.0
DI88	36.4	49.2	46.8	28.5	1.0	2.4	1.5	1.2	1.9	1.7
GE41	36.3	44.3	45.5	28.2	1.2	1.5	0.8	1.2	1.8	0.7
PE151	40.8	48.5	48.4	34.5	2.0	2.1	1.5	1.9	2.6	1.8
BO165	40.2	49.6	48.6	31.4	1.2	2.5	1.2	1.3	2.1	1.1
CI27	39.5	49.9	48.9	34.1	2.1	2.6	0.8	1.3	1.8	1.0
LO61	39.8	48.4	47.8	32.7	1.4	2.5	1.2	1.6	2.3	1.2
NE74	45.1	56.8	54.4	37	0.8	2.3	1.5	1.5	2.5	1.9
BR135	42.9	55	54.2	34.1	1.6	2.3	2.7	1.9	2.4	3.6
WI241	43.3	53.8	53.7	36.5	0.6	1.4	1.5	0.6	1.5	1.4
MA329	36.9	48.1	46.9	32.1	0.7	1.8	1.3	1.2	2.1	1.3
MC156	34.7	44.3	43.8	29.5	0.5	1.9	1.2	1.1	2.1	0.8
RE110	38.6	48.4	47.3	35	1.3	3.1	1.0	1.8	2.3	1.3
ZU16	40.9	52	49.8	32.7	1.8	2.3	1.3	1.5	2.0	1.4

Appendix 7: Non-expansion patient's final intermolar widths and alveolar bone widths after orthodontic treatment (mm):

Patient ID	Palatal Root Intermolar Width	Mesiobuccal Root Intermolar Width	Distobuccal Root Intermolar Width	Interapical Intermolar Width	Tooth#3 Mesiobuccal Bone Thickness	Tooth#3 Distobuccal Bone Thickness	Tooth#3 Palatal Bone Thickness	Tooth#14 Mesiobuccal Bone Thickness	Tooth#14 Distobuccal Bone Thickness	Tooth#14 Palatal Bone Thickness
SC142	39.7	46.2	48.5	33.4	2.0	2.6	1.9	2.0	2.4	1.9
HA340	42.4	52.1	52.0	37.0	1.0	2.0	0.4	0.8	1.3	0.3
BI60	39.9	50.1	49.1	33.6	0.7	2.3	0.6	0.8	1.7	1.1
KO107	37.2	47.3	46.7	28.9	1.3	1.5	0.7	0.7	2.1	0.8
CO237	40.0	49.6	49.1	35.4	2.0	1.8	1.4	1.9	2.9	1.2
BE161	33.1	43.4	43.8	28.1	1.7	2.1	1.2	1.6	2.1	1.3
IS22	43.1	51.5	52.6	35.5	1.7	2.4	2.4	1.9	2.4	2.4
HE106	38.0	47.5	47.8	30.0	1.6	2.4	1.1	1.7	2.0	1.1
PA148	36.0	45.7	44.7	30.9	0.6	2.5	0.6	0.5	2.4	0.7
JO97	39.1	46.2	47.9	30.2	0.7	0.9	1.5	0.7	2.1	1.6
MU83	42.1	52.9	50.7	33.4	1.4	3.1	1.0	1.6	3.0	0.7
EV17	40.4	49.2	49.3	31.2	2.5	2.1	1.9	2.4	2.7	2.8
BA175	34.8	40.8	43.1	29.7	1.8	2.6	1.1	0.8	2.1	1.4
HA295	37.9	47.3	47.6	31.1	0.7	1.5	1.0	1.0	2.3	0.8
PE149	42.3	50.5	51.9	34.8	1.4	2.2	0.5	1.6	2.2	1.0
SC151	42.6	50.7	49.3	36.9	1.6	1.7	1.7	2.1	1.8	2.7
KO82	39.1	48.4	46.6	31.0	2.3	2.6	1.1	2.7	2.7	0.9
DI88	37.8	49.9	47.1	28.2	1.0	1.6	1.2	1.1	1.7	1.0
GE41	35.0	45.3	45.0	26.8	1.0	1.6	0.2	1.2	1.2	0.3
PE151	39.3	49.8	48.0	32.5	1.3	2.5	1.3	1.3	2.3	1.1
BO165	41.3	49.7	48.8	33.6	1.1	1.8	1.7	1.2	1.7	1.3
CI27	37.2	51.2	49.9	33.2	1.2	2.8	1.5	2.0	2.9	1.2
LO61	39.1	49.8	47.9	31.6	1.3	2.5	0.9	1.3	1.8	1.0
NE74	46.0	55.3	54.5	37.8	1.4	2.1	1.7	2.3	2.8	1.7
BR135	42.9	54.3	54.1	34.5	1.7	2.5	2.4	2.5	2.5	2.7
WI241	41.2	52.2	51.9	34.4	0.7	1.4	0.9	0.5	1.6	1.4
MA329	38.2	50.0	47.3	32.8	0.7	2.6	0.5	1.3	2.3	0.7
MC156	35.0	44.7	43.6	28.6	0.8	2.0	1.0	1.2	2.4	0.7
RE110	38.1	47.1	46.2	34.1	1.4	2.8	0.4	1.8	3.0	0.5
ZU16	40.5	50.7	50.1	32.9	1.6	2.4	1.0	1.2	2.7	1.2

Appendix 8: Sample size calculation:

A minimum sample of 25 patients were needed for the case-control part of this study (assuming an effect size of 0.6 and a standard deviation of 0.76).

A minimum sample of 25 patients were needed for the descriptive part of this study (assuming a confidence interval width of 0.6 and a standard deviation of 0.76).

The effect size was attained from Leung et al.[34] who found that alveolar bone height can be measured to an accuracy of 0.6 mm. The standard deviation was taken from Rungcharassaeng et al[26] who found that this was the standard deviation when measuring alveolar bone around the maxillary first molar root.

All eligible subjects who met the inclusion and exclusion criteria were included. The total number eligible subjects included in this study was 30.

Case-control study (2 tailed alpha of 0.05, and beta of 0.20):
Effect size (E): 0.6
Standard deviation (S): 0.76
E/S = 0.6/0.76 = 0.79

Descriptive study (95% confidence interval):
Desired total width (W): 0.6
Standard deviation (S.D.): 0.76
0.6/0.76 = 0.79.

Appendix 9: Interapical width analysis

METHOD

Once all the measurements for intermolar width between the mesiobuccal, distobuccal and palatal roots of contralateral teeth were measured and recorded, the axial plane was then reset so that the most apical tip of the maxillary right and left first molar palatal root was visible. The length of a line drawn between the right and left palatal root apices was measured in millimeters.

RESULTS

The intraclass correlation coefficient between repeated measures was >0.9, well within the range of acceptability.

The average interapical width for the expansion group was 33.3 mm. This average was the same pretreatment and postreatment.

The average interapical width for the non-expansion group was 32.3 mm. This average was the same pretreatment and postreatment.

In both the expansion and non-expansion groups, there was no statistically significant difference in inter-apical molar width measures at the apex of the palatal root between the groups and no statistically significant change in this measurement within the groups ($P \leq 0.05$). In other words, there was also no statistically significant change in the inter-apical width between or within the two groups.

DISCUSSION

Although the position of the crowns between the two groups was different, the position of the root apices was not. At the end of treatment, after arch wire expansion and buccal tipping of the molars, the expansion and non-expansion groups had no statistically significant difference between them in any intermolar width measurement whether it was assessed at the level of the crown, at the level of the furcation of the root, or at the level of the palatal root apex. In other words, the crowns and roots of all patients at the end of treatment were now in the same relative position in the transverse dimension of space, regardless of which of the two groups they ascribed to. The fact that there was no statistically significant change in the distances between the palatal root apices within or between the groups as a result of treatment reaffirms this.

Furthermore, the inter-apical distance of the palatal roots was surprisingly similar for both the expansion and non-expansion groups before and after orthodontic treatment: with a maximum difference of only 1.08 mm. Further evaluation of the expansion group reveals that these patients initially started with more upright maxillary first molars. This is evidenced by the fact that the difference in intermolar width between the expansion and

non-expansion group at the initiation of treatment was statistically significant, even though the interapical width was not.

Ballanti et al. [64] also measured the intermolar width at the apex of the palatal root, but did so in patients who had undergone rapid maxillary expansion. They found a statistically significant increase in this measurement in all 17 subjects in their sample. This is once again consistent with logic: arch wire expansion tips teeth and hence does not change the position of the palatal root apex, verses rapid palatal expansion which has skeletal effects and hence does separate the palatal root apices from one another.

When one looks at the ratio of the initial inter-apical distance (measured between the apices of the palatal root on the CBCT) to the initial inter-coronal distance (measured between the central fosses on the dental casts) an interesting trend appears. The ratio in the expansion group was 0.8 before treatment, and 0.7 after orthodontic treatment. For the non-expansion group, this ratio was 0.7 before and after treatment. The trend appears to be even more evident in the extremes, in other words, patients who had a ratio of 0.9 or 1.0 all belonged to the expansion group, and patients with a ration of less than 0.65 all belonged to the non-expansion group. Ballanti et al. 64 calculated this same ratio in their study sample and found that this ratio was 0.8 mm before rapid-palatal expansion. They found that this ratio did not change after expansion, since, in contrast to the expansion in our study which resulted from dental tipping, in rapid palatal expansion, but the crown and the root move buccally. Further investigation may be warranted as possibly this may be a future way to differentiate patients who need orthodontic vs. orthopedic vs. surgical expansion.

Also, when all patients were pooled and placed in ascending order according to initial inter-molar width, it is interesting to note that all patients with an initial intermolar width of $\leq$37.50 underwent orthodontic expansion of no less than 2.5 mm. Perhaps this number is the threshold below which expansion is needed. Again, a larger sample size is needed to make a definitive conclusion.

CONCLUSION

Although at the crown level of the maxillary first molar there was a statistically significant increase in arch width, as measured between central fosses and between roots at the level of the furcation, there was no change in width at the level of the apex of the palatal root. The above indicates that the result of arch wire expansion was pure tipping. The ratio of the inter-apical (as measured from the CBCT) to intermolar (measured from the dental plaster models) widths for the non-expansion group was 0.7 pre and post treatment, and for the expansion group was 0.8 pre-treatment and 0.7 post-treatment. This warrants further study, as it may elucidate the parameters for when orthodontic vs. orthopedic vs. surgical intervention is necessary.

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