Evaluation of Periodontal Changes after Miniscrew Assisted Rapid Palatal Expansion in Adults

by

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Abstract

Introduction:

Miniscrew Assisted Rapid Palatal Expanders (MARPE) have been recently utilized in adult patients to correct maxillary transverse deficiency. Clinical research on the effect of different MARPE designs on periodontium of neighbouring teeth has been limited. The aim of this research was to compare the Moon expander and the Dresden appliance in terms of their respective effects on periodontium of neighbouring teeth. Changes in risk factors attributed to gingival recession was also analyzed.

Methods:

In this retrospective study, Cone Beam Computer Tomography (CBCT) records, intraoral scan records (STL), and intraoral photographs were taken from patients undergoing expansion with either Moon or Dresden appliances. Records were taken at T_1 (pre-expansion) and T_2 (post-expansion) timepoints. Maxillary first molars (mid-mesiobuccal root), first premolars (mid-buccal root) and second premolars (mid-buccal root) were analyzed. Changes in buccal bone marginal level, buccal bone thickness at 3 and 6 mm from CEJ, buccal gingival level, and gingival thickness at 2mm from CEJ were analyzed using CBCT and superimposed STL data.

To assess for changes in risks for further recession, photo-analysis was performed on the photographs taken at T_1 and T_2. Changes in gingival recession, keratinized tissue thickness, gingival inflammation, and keratinized tissue width were scored. Data were compared between the two groups and analyzed.

Results:

Data obtained from nine adult patients treated using the Dresden appliance and eleven adult patients treated with the Moon expander were analyzed. The results showed that after maxillary expansion, the buccal bone thickness at 6mm from the CEJ was reduced by 0.31mm around the first maxillary molars (p-value <0.03), regardless of the type of appliance used. Changes in other osseous and gingival dimensional parameters (from T_1 to T_2) were not statistically different between the two appliance groups. Changes in buccal bone thickness at 3mm from CEJ correlated with gingival thickness changes at 2mm from CEJ around the second premolars in the Dresden appliance group. Nevertheless, changes in other gingival parameters did not correlate with changes in osseous parameters in both groups. Findings also indicated that incidence of gingival inflammation and recession increased in both treatment groups. However, distribution of changes in factors associated with development of gingival recession was not statistically significant between the two groups.

Conclusion

Within timeframe of this study, while buccal bone thickness at 6mm from CEJ was reduced around maxillary first molars after maxillary expansion, effect of appliance design was not found to be significant for any of the measured parameters. Both appliances equally affect the scored risk factors for further gingival recession.

Preface

This thesis is an original work completed by Ali Tanara. No part of this work has been previously published. The ethics approval for this thesis was obtained from the Research Ethics Board (Pro00084145) on August 06, 2020, from the University of Alberta.

Dedication

This work is dedicated in loving memory of my late grandmother, Mamani, who passed away during the final year of my periodontology training. You helped raising me and guided me in life for as long as I remember. You will always hold a special place in my heart.

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I extend my heartfelt gratitude to my supervisor, Dr. Monica Gibson, for her unwavering support as my supervisor, program director, and mentor throughout this program. Her dedication to my growth as a researcher and clinician has been truly exceptional.

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Nomenclature

List of Abbreviations

AP	Apex of the root
BASS	Before and After Scoring System
BBML	Buccal Bone Marginal Level
BBT3	Buccal bone thickness 3 mm from Cemento-Enamel Junction
BBT6	Buccal bone thickness 6 mm from Cemento-Enamel Junction
BS	Bleeding Score
CAL	Clinical Attachment Level
CBCT	Cone-Beam Computed Tomography
CEJ	Cemento-Enamel Junction
CJAP	Distance from Cemento-Enamel Junction to apex of the root
DICOM	CBCT imaging output data
FGM	Free Gingival Margin
GL	Gingival Level
GR	Gingival recession
GTRP2	Gingival thickness 2mm from Cemento-Enamel Junction
INF	Inflammation
KT	Keratinized tissue
KTT	Keratinized tissue thickness
KTW	Keratinized tissue width
M1	Maxillary first molar
MARPE	Miniscrew Assisted Rapid Palatal Expansion
MGJ	Mucogingival Junction
PD	Probing Depth
PDL	Periodontal Ligament
PES	Pink Esthetic Score
PM1	Maxillary first premolar
PM2	Maxillary second premolar
RES	Root Coverage esthetic Score
RP3	Root point 3mm from Cemento-Enamel junction
RP6	Root point 6mm from Cemento-Enamel junction
RPE	Rapid Palatal Expansion
SARPE	Surgically Assisted Rapid Palatal Expansion
STL	Intraoral scan output data
TAD	Temporary Anchorage Devices

Chapter 1 - Introduction and Problem statement

1.1 Introduction

1.1.1 Maxillary Transverse deficiency

Maxillary transverse deficiency is a common developmental condition that may result in severely constricted maxilla, leading to significant cosmetic or functional problems.[1] Diagnosis of maxillary transverse deficiency is made when dimensions of the narrow maxilla is determined to be incongruent to other facial dimensions.[2] As a result, patients who suffer from this condition are also challenged with posterior cross bites, when maxillary teeth are lingually positioned in relation to teeth in the mandibular arch. To correct the maxillary transverse deficiency, treatment is commonly performed early in adolescence prior to maturation of the maxillary palatine sutures via the use of maxillary palatal expanders. However, there are side effects associated with using maxillary palatal expanders such as tipping and extrusion of the anchor teeth, periodontal trauma, as well as buccal root resorption due to the high forces applied to the anchored teeth. Furthermore, Studies by Steiner et al.[3] and Wennström et al.[4] have discussed the possibility of gingival recession and subsequently connective tissue attachment loss in conjunction with labial and/ or buccal bodily movement or tipping of teeth in Monkeys. Moreover, in areas of minimum width of keratinized gingival tissue, labial movement of teeth can lead to loss of buccal bone and gingiva, both of which are important elements of periodontium around teeth.[5-8]

1.2 Periodontium and its response to orthodontic forces:

The periodontium of a tooth consists of gingiva, periodontal ligament, and alveolar bone proper that connect to the root surfaces of the tooth. This attachment apparatus is the connection of the respective tooth to the jawbone, which allows for maintenance of the health of the surface of the masticatory soft tissues of the oral cavity.[9]

Periodontal ligament contains blood vessels, nerve endings, and collagen fibers that connect the root cementum to the alveolar bone in a space of about 0.25-0.5mm circumferentially around the tooth. This ligament responds to external forces depending on the magnitude and duration of forces applied.[2, 10] In mastication, forces from 1kg to 50kg are applied in 1 second or less.[2] During this period, periodontal ligament (PDL) transmits these types of forces to the alveolar bone. This transmission of forces produces a piezoelectric current, which helps maintain bone health by repair and regeneration.[2]

However, when external forces are sustained, the physiological response of periodontium is different.[2, 10] These forces, which include orthodontic forces, cause a tooth to shift position within the PDL space and induce compression and stretching of the PDL ligament.[2] Such forces later lead to changes in blood flow as well as release of chemical cytokines, which regulate the activity of bone remodeling apparatus. Moreover, fibroblasts, osteoblasts, and osteoclasts are proliferated via such signals and begin work.[2, 10] Therefore, alveolar bone is remodeled via resorption of bone that is in area of compression forces, while bone is formed in an area where there are stretching forces. This combined effect leads to orthodontic movement of teeth.[2]

1.2.1 Gingiva, its components and effect of orthodontic treatment

Gingiva is comprised of three components: 1) Free (marginal) gingiva, 2) attached gingiva, and 3) interdental gingiva.[9] Free (Marginal) gingiva immediately surrounds the tooth, while attached gingiva is located more apically and separated by the free gingival groove in 50% of the teeth.[11] Moreover, in health, both free gingiva and attached gingiva are coral pink, keratinized, and are separated from non-keratinized alveolar mucosa in the buccal aspect of all teeth and lingual aspect of mandibular teeth by the mucogingival junction. Palatal mucosa is keratinized and continuous with gingiva around teeth with no demarcation line.[9] Figure 1.1 illustrates different components of periodontium:

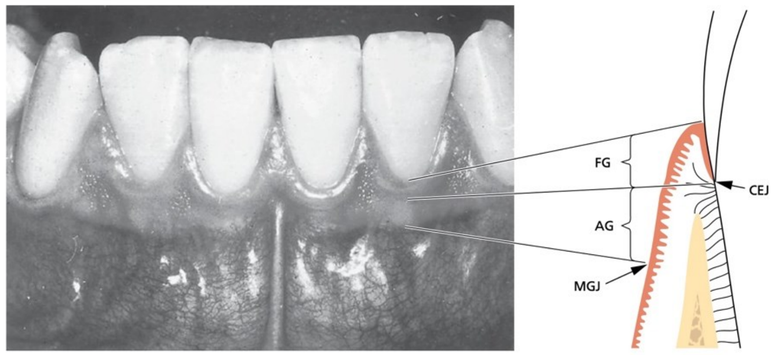


Figure 1.1 Schematic of periodontal anatomy.

FG: free gingiva, AG: Attached gingiva, MGJ: Mucogingival junction CEJ: Cemento-Enamel junction of the tooth. Adapted from Lindhe et al., 2015[9]

Gingiva provides a physical seal around the tooth that protects the underlying attachment and alveolar bone against microbial invasion.[11] Gingiva further plays a defensive role fight against microbial invasion by modulating immune response.[12] The signaling initiated by this response leads to gingivitis or inflammation within the gingival tissue and attracts immune cells allowing the body to mount attack against the invading microbes.[12] If the immune system is successful in repelling the microbial invasion, gingivitis resolves. Otherwise, it may progress to further gingival breakdown and eventually leading to periodontitis. Such a process includes the breakdown and loss of periodontium including underlying attachment as well as the alveolar bone.[13]

Marginal tissue Recession

According to American Academy of Periodontology, gingival recession is the migration of soft tissue margin apical to Cemento-Enamel junction (CEJ) of the tooth.[9] Additionally, gingival recession is associated with Clinical Attachment Levels (CAL), which is influenced by the underlying bone levels and architecture. Clinical attachment level (CAL) is defined as the distance from the most coronal aspect of soft tissue attachment to the tooth using the Cemento-Enamel junction of the tooth as the reference point. It is clinically calculated by addition of clinical probing depth to the amount of recession noted on the tooth.[9]

Orthodontic treatment could lead to bony dehiscence, inflammation, and gingivitis due to plaque accumulation.[14-16] This could further lead to marginal tissue recession. Other causes of marginal tissue recession include gingival inflammation due to untreated periodontal disease, aggressive tooth brushing, soft tissue thickness, tooth malposition, aberrant frenum attachment, friction from soft tissues, and iatrogenic causes such as trauma.[17, 18] Pathological marginal tissue recession leads to loss of keratinized tissue width, thereby gingival height and eventually result in a situation where total loss of keratinized tissue is observed.

According to the meta-analysis conducted by Chambrone and Tatakis, untreated buccal marginal recession has been associated with increased recession defect in long term follow up, leading to increased loss of attachment apparatus.[19] Therefore, prevention of recession is of utmost interest.

Several factors are affected by the orthodontic tooth movement such as gingival thickness, keratinized tissue width and bone morphology.[20] These parameters also play a role on how tissues respond to inflammation. Therefore, the degree to which these variables are affected by orthodontic treatment is of utmost interest.

1.2.2 Periodontal variables affected by orthodontic intervention

Buccal bone morphology and dehiscence:

Orthodontic position of the tooth within the alveolar bone is related to the thickness of the buccal bone and overlaying gingiva. Furthermore, the more the tooth is buccally positioned, the thinner buccal bone might be.[21] Some studies have associated the presence of thin buccal bone with gingival recession,[22] while others have not found this association.[21]

If the tooth is moved outside of the alveolar house, this may lead to loss of buccal bone in thinner areas and could potentially lead to coronal loss of bony marginal level. Presence of this bony dehiscence has been associated with marginal gingival tissue recession.[23] In a study conducted by Löst, 113 teeth in 27 patients were examined. Results showed that for every 1mm increase in recession depth, there was a 0.98mm corresponding increase in alveolar bone dehiscence.[23] Therefore, the underlying bony architecture, including presence of dehiscences and fenestrations, can be related to the architecture of the overlying gingival tissue and vice-versa.[20, 24]

Keratinized and attached tissue width:

Presence of 2mm of keratinized tissue width with 1mm of attached tissue is considered adequate gingiva that is desirable for maintenance of periodontal health as per 2017 World Workshop.[20] While periodontal health is still maintainable in presence of inadequate gingiva in presence of adequate oral hygiene,[25] more keratinized tissue width is desirable when teeth are subject to orthodontic forces. Furthermore, systematic review done by Kim and Neiva based upon historical clinical observations concluded that there is a higher probability of recession in areas of less than 2mm of keratinized tissue width after orthodontic tooth movement.[26]

Gingival thickness

Gingival thickness is highly variable and is dependent on several factors including tooth size, shape, type, location, as well as presence of inflammation.[27] In addition, studies have concluded that age and gender also contribute to the amount of gingival thickness.[28]

Claffey and Shanley classified gingiva as thin when thickness was ≤1.5mm and thick when it was ≥2.0mm.[29] However other investigators have classified gingiva as thin, when its thickness is ≤1.0mm and thick when it has >1mm thickness.[30]

Investigation by Goaslind et al.[31] determined that using a transmucosal probing technique on selected teeth, free gingival thickness averaged 1.56mm± 0.39mm, attached gingival thickness averaged 1.25mm±0.42mm, and total mean for all areas measured was 1.41mm. More recently, a systematic review by Zweers et al.[32] determined that gingival thickness ranges from 0.63±0.11mm to 1.79±0.31. Overall, thinner gingival was found around cuspids ranging from 0.63±0.11mm of thickness to 1.24±0.35mm of thickness with an average of 1.24±0.35mm of thickness.[32]

As described by Zweers et al.[32] and included in the proceedings of the 2017 World Workshop on Periodontal disease and conditions,[20] periodontium can be categorized based on gingival thickness, amount of keratinization, shape of the teeth, and scalloping. Such phenotypes can be classified into three categories:

1) Thin scalloped phenotype: associated with slender and triangular crowns, subtle crevicular convexity, interproximal contacts close to the incisal edges, narrow width of keratinized tissue, and thin gingiva that is overlaying a thin alveolar bone. Papilla is generally scalloped in this group.
2) Thick Flat phenotype: this phenotype is associated with square shaped teeth with pronounced cervical convexity, large interproximal contacts that are closer to middle third of the crown. Wider band of keratinized tissue, thick fibrotic gingiva, and underlying thicker alveolar bone is also seen in this group. Papilla is generally flat in this group.

3) Thick Scalloped phenotype: This phenotype includes features of the above two phenotypes. Particularly, thick fibrotic gingiva in combination with slender teeth, narrow zone of keratinized tissue, and scalloping of papilla are noted.

Thin gingival phenotypes have generally been associated with gingival recession more than thick gingival phenotypes.[20] Such recession may occur because of inflammation, trauma, or orthodontic forces. Inflammation and trauma cause loss of tissue because of tissue damage and injury, while orthodontic forces could lead to the loss of tissue due to the physiological response as part of orthodontic tooth movement. Such effects may be especially important in treatment of orthodontic conditions such as Maxillary transverse deficiency, which may require significant orthodontic buccal movement of teeth.

1.3 Treatment of Maxillary Transverse Deficiency:

Rapid palatal expansion (RPE) is a technique used to correct maxillary transverse deficiency in adolescents. In this technique, expander appliances typically anchor to teeth on either side of the maxillary palatine shelves and results in expansion of the palate.[33] This rapid expansion protocol involves activation of the appliance up to two quarter turns of the screw (0.5mm/day) with higher force of 10 to 20 pounds on the suture, which results in up to a centimeter of expansion in a matter of 2 to 3 weeks.[2]

While this technique allows for orthopedic expansion of maxilla in younger patients, as the patient's palatine suture matures, using RPE appliances may provide undesirable outcomes. Such side effects include tipping or bodily movement of teeth, bone dehiscence, gingival recession, and buccal crown tipping of the anchored maxillary teeth.[14] Therefore, RPE could negatively affect periodontal health and stability in adults.

To minimize such effects, Surgically Assisted Rapid Palatal Expansion (SARPE) has been used for treatment of maxillary transverse deficiency in adult patients. This surgical treatment involves performing osteotomies in the maxillary suture in addition to an RPE appliance or using distraction osteogenesis,[34, 35] Protocol to this type of expansion includes reflection of soft tissues of hard palate, separation of palatal shelves via use of chisels or burs. Then, depending on the type of appliance used, miniscrews may be inserted in the palate in leu of anchoring teeth. While the orthopedic effect of SARPE is reported to be more than non-surgical expansion in adults, increase in costs, morbidity, patient discomfort, and surgical complications such as infection, as well as the need for additional hospitalization and healing may present themselves as consequences of SARPE procedure. Such outcomes may deter patients and practitioners from selecting SARPE as a mode of treatment and make them accept compromises in orthodontic outcomes of adult patients.

More recently, however, it has been suggested that a true palatine suture fusion does not occur and despite being difficult, palatine expansion without the need for surgical intervention is possible.[36] Notably, Miniscrew Assisted Rapid Palatal Expanders (MARPE) utilize temporary anchorage devices (TADs) that directly anchor into the palatine shelves and attempt to induce expansion directly on the bone with less or no reliance on anchoring teeth and minimal surgical intervention.

1.4 Designs of MARPE appliances:

Since their inception, MARPE devices of various designs and features have been introduced.[37] Some MARPE appliances, namely Type 1 appliances use Miniscrews implanted beside the medial palatine suture only, while others such as Type 2 appliances utilize miniscrews implanted at the sloped surface of the palate instead (Dresden appliance). Furthermore, Type 3 appliances take advantage of miniscrews that are implanted beside the median palatine suture as well as bands on contralateral teeth such as molars and premolars (Moon expander). Figure 1.2 illustrates difference types of MARPE Appliances:

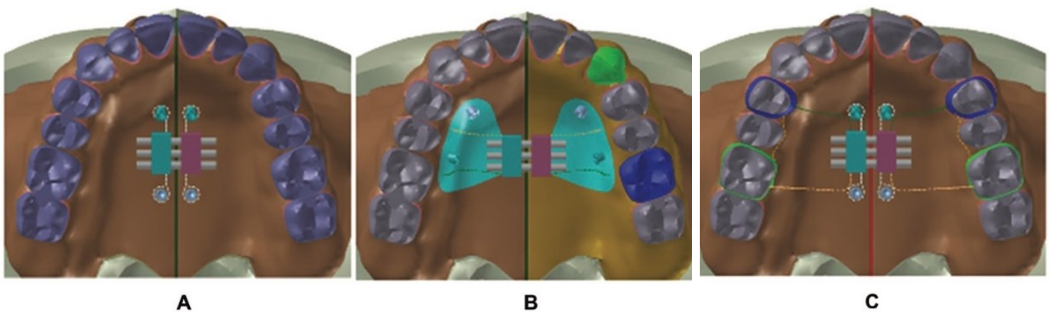


Figure 1.2 Types of Miniscrew Assisted Rapid Palatal Expansion (MARPE) deveices

(A) Type 1 MARPE design with miniscrews placed 3mm lateral to mid-palatal suture, B) Type 2 MARPE design with miniscrews placed at the palatal slope. C) Type 3 MARPE design with combined expander with additional conventional hyrax arms on the anchoring teeth. Adapted from Lee et al. ,2014[37]

The main difference between the Dresden and the Moon expander is that the Dresden expander has no tooth anchorage and has two miniscrews that are inserted on the palatal alveolar bone, whereas the Moon expander has bands on maxillary first molars and four miniscrews that are placed paramedial to the mid-palatal suture. Due to the design differences between these appliances, effects exerted by these appliances on the periodontium of the neighboring teeth may be different.[37]

While different MARPE appliance designs may be fabricated and utilized for the same purpose of maxillary expansion, their effects on periodontium of neighboring teeth may provide a rationale for clinicians to favour one appliance over another. Currently, clinical studies that evaluate periodontal effects of Type II and Type III MARPE appliances on adults have been limited. Therefore, conducting such studies can be beneficial to help clinicians make a better decision when selecting the design of the MARPE appliances, particularly in adults who may be more susceptible to unwanted periodontal changes following maxillary expansion.

1.5 Aim of the study

The aim of this study is to retrospectively compare the effects of orthodontic expansion appliances (MARPE) (namely Moon and Dresden appliances) on periodontal condition of teeth in adults, via the use of Cone Beam Computed Tomography (CBCT), intraoral imaging, and intraoral scans. In this analysis, buccal bone thickness, buccal bone marginal level, and gingival phenotype of adult patients who have undergone palatal expansion using bone-anchored maxillary expanders will be evaluated before and after maxillary expansion. Therefore, the purpose of this retrospective study is to satisfy the following research objectives:

<u>Primary Objective:</u>

- To determine differences in buccal bone dimensional changes between the two MARPE groups.

<u>Secondary Objectives:</u>

- To determine gingival dimensional changes between the two MARPE appliance designs.
- To determine if there are any correlations between osseous and gingival changes between the two groups.
- To determine if expansion with either appliance would increase risk factors for recession.

1.5.1 Research questions

To accomplish objectives outlined above, several research questions were formulated as follows:

1) Do buccal bone thickness and marginal levels around the teeth adjacent to MARPE appliances change after the maxillary expansion is performed?
2) Are these osseous changes affected by the appliance design?
3) Do buccal gingival thickness and gingival levels around teeth adjacent to MARPE appliances change after the maxillary expansion is performed?
4) Are these gingival changes affected by the appliance design?
5) Are the osseous and gingival changes correlated between the two appliances?
6) Does expansion with either appliance change presence of the risk factors for the further recession?

Chapter 2 - Literature review: Periodontal effects of palatal expansion.

2.1 Orthodontic tooth movement and recession

Frontal movement of anterior teeth or buccal movement of posterior teeth may lead to loss of attachment and gingival recession.[8, 38, 39] As such, in areas with inadequate keratinized gingiva, gingival grafting procedures prior to initiation of orthodontic therapy have been suggested.[8, 40, 41] Furthermore, if the tooth is moved outside the alveolar housing, bony dehiscence can be resulted, which may predispose the site to further gingival recession at that site. Conversely, if the tooth is orthodontically moved into the alveolar housing, it may result in bone formation at the site of previous dehiscence,[42, 43] thereby reversing gingival recession and causing attachment gain.[9]

Animal Studies on monkeys by Batenhorst et al.[44] and Steiner et al.[3] demonstrated loss in gingival marginal levels and attachment due to facial tipping, extrusion, or bodily movement of teeth. Nevertheless, similar experiments by Karring et al.[43] on Dogs and by Rateitschak[45] on humans did not produce such effects. Therefore, additional factors such as the amount of orthodontic tooth movement, presence and amount of plaque and inflammation, and amount of gingival thickness may provide explanation to why some sites may be resistant to gingival recession or attachment loss.[9]

2.2 Rapid Palatal Expansion (RPE) and its periodontal effects

According to a study by Baccetti et al.,[46] they investigated the use of maxillary expansion appliances (Hass appliance) before and after pubertal growth peak. Results showed that using RPE before peak of skeletal maturation produced more skeletal effects than using RPE after skeletal maturation.

In a study by Garib et al.,[14] induced bone dehiscence on the buccal aspect of anchorage teeth used by RPE in children was reported. Their study consisted of eight patients (11-14 years of age) and they used Hass expander (tooth-tissue born expander) or hyrax expander (tooth born) to rapidly expand the maxilla with unilateral or bilateral crossbites. Results showed that buccal bone plates were reduced from 0.6 to 0.9mm, while lingual bone plate thickness increased 0.8 to 1.3mm. This increase in lingual bone plate thickness of posterior teeth was higher in tooth-born group than tooth tissue born group.[14] Additionally, RME caused bone dehiscence on buccal aspect of anchoring teeth (7.1±4.6mm at the first premolars, and 3.8±4.4mm at the mesio-buccal area of the first molars). Lastly, the tooth-born expander produced greater reduction of buccal alveolar crest level in first premolars than did the tooth-tissue born expander. This was more prominent among subjects with thinner buccal bone plates.[14] In another study by Rungcharassaeng et al., 2007,[47] the effects of RPE on buccal bone in teenagers (mean age 13.8± 1.7 years) were studied. In this study, Hyrax expanders were utilized, and it was found that buccal crown tipping, loss of buccal marginal bone, and thinning of buccal bone were immediate effects of RPE. Factors such as age, amount of appliance expansion, initial buccal bone thickness, and differential expansion had significant correlation with the amount of buccal bone changes and tipping,[47] Nevertheless, rate of expansion and retention time were not associated with buccal bone changes and tipping in contrast with later study by Sperl et al..[48]

Sperl et al.[48] performed a retrospective CBCT analysis of 45 children with mean age of 13.01±1.33 years, who were treated with Hyrax expanders. In this study, Hyrax expanders with soldered wires along the palatal surfaces for even dispersion of force across all maxillary molars and premolar were utilized. Upon CBCT measurement of buccal bone thickness before and after maxillary expansion, the investigators found that RME and fixed appliances can result in significant reduction in buccal bone thickness of anchoring teeth regardless of age, post expansion retention time, and overall treatment time. The most common bony defect noted was fenestration seen in over half of the patients. Dehiscence frequency was at 2% with mesio-buccal root of maxillary first molars most affected. Furthermore, the amount of buccal bone thickness loss increased from -0.51 ±0.43 mm at 4mm apical to CEJ to -0.98±0.64mm at 8mm apical to CEJ.[48]

2.3 MARPE treatment and its periodontal effects in simulation studies

Lee et al.[37] compared different designs of MARPE appliances on the basis of stress distribution and displacement using a three-dimensional finite-element (FE) analysis. In this investigation, the authors found that Type 2 MARPE devices exerted the least stress concentrations around anchorage teeth and lead to bony expansion of alveolus without tipping of the teeth.[37] While this FE analysis specifically looked at stress distribution and tipping of the teeth using MARPE appliances, the effect of these devices on periodontium in clinical trials on live patients have been limited.

2.4 MARPE treatment and its periodontal effects In-vivo studies

Gunyuz et al.[49] compared the effect of both tooth-born and tooth-bone-borne rapid expanders (MARPE Type III) in thirteen (8 girls, and 5 boys) and twelve (6 girls and 6 boys) adolescent patients. CBCT imaging was used prior to and three months after maxillary expansion. In this study, anchor teeth were first molars and premolars. In both groups, buccal bone thickness decreased by 0.7 mm to 1.2mm at first molars, whereas lingual bone thickness increased. Surprisingly, buccal bone thickness of first premolars in the MARPE appliance was unchanged, while in Hyrax appliance group, there was a decrease. As a result of this, authors of this study suggested that MARPE appliances of this design may be beneficial to adolescent patients with a higher risk of periodontal loss at the first premolar area.[49]

Park et al.[50] investigated skeletal and dentoalveolar changes of fourteen young adult patients (16-26 years of age with a mean age of 20.1 year), who were treated with type III MARPE appliance using CBCT imaging only. In this investigation, buccal bone thickness and height of alveolar crest decreased by 0.6-1.1mm and 1.7-2.2mm, respectively. These findings were comparable to those by Lim et al., who investigated the effect of MARPE appliance in twenty-four young adults (mean age 21.6 years). In this study, Lim et al.[51] evaluated CBCT records and found a decreased in buccal bone thickness (average -0.52 ±0.38mm for first premolars, -0.09 ±0.39mm for second premolars, and -0.36±0.29mm for first molars) and an increase in palatal bone thickness (average 0.92±0.77mm for first premolars, 0.39±0.46mm for second premolars, and 0.56±0.61 for first molars) around anchoring teeth, immediately after maxillary expansion. There was also a significant loss of buccal alveolar crest level around anchoring teeth (loss of 2.27±2.99mm for first premolars, 0.66±0.62mm for second premolars, and 0.74±0.93mm for first molars) immediately after maxillary expansion. However, some of the changes noted immediately after expansion had reversed after a one-year follow-up measurements were performed. Specifically, the final buccal bone thickness changes compared to pre-expansion was determined to be -0.26mm±0.38mm for first premolars, -0.36±0.60mm for second premolars, and -0.13±0.59mm for first molars. In terms of buccal bone crest level, the amount of bone loss was 1.54±2.00mm for first premolars, 0.21±1.05mm for second premolars and 0.33±0.67mm for first molars at the one year follow up.

In a retrospective pilot study by Ngan et al.,[52] skeletal, dentoalveolar, and periodontal changes following MARPE appliance in skeletally mature patients were investigated. Eight subjects with cervical vertebral maturation score of 4 and mean age of 21.9 years participated in this study. Maxillary skeletal expander, a type III MARPE appliance, was utilized. Following analysis of pre and post expansion CBCT records, it was found that mid palatal suture expansion was achievable in 100% of the skeletally matured young adults. Interestingly, total expansion was comprised of 41% skeletal expansion, 12% alveolar bone bending, and 48% tipping of the teeth.

Moreover, buccal alveolar bone thickness of the right and left premolars had an average decrease of 0.54mm and 0.68mm, respectively. These values corresponded to an average of 39% buccal bone reduction at premolars and molars.[52]

Lastly, Moon et al.[53] evaluated molar inclination and surrounding alveolar bone of young adolescents who underwent maxillary expansion using two different MARPE designs. Group 1 were treated with MSE appliance (Type III MARPE) (mean age of 19.2±5.9 years) and group 2 were treated with C Expander (Type II MARPE) (mean age 18.1 ±4.5 years). CBCT scans were utilized in both groups to compare the transverse, skeletal, and dental expansion, alveolar inclination, tooth axis, and buccal alveolar bone height, thickness, as well as presence of dehiscence before and after treatment on maxillary first molars. Greater dental expansion was seen in the MSE group, while skeletal expansion was not different. However, the C expander group had more alveolar bone inclination change and the MSE group had more buccal tipping of the anchoring teeth. Furthermore, Alveolar bone level loss and thickness loss, and presentation of dehiscence were greater for MSE group. Development of dehiscence did not differ between groups.[53]

Chapter 3 - Methods

3.1 Methods

This retrospective randomized clinical trial study was conducted at the University of Alberta, with ethics approval from the University of Alberta Research Ethics Board (Pro00084145). Patient records from twenty-three patients who underwent Miniscrew Assisted Rapid Palatal Expansion (MARPE) (using either Dresden or Moon Expander) were analyzed.

3.2 Inclusion and exclusion criteria (Patient Criteria and Tooth Criteria)

3.2.1 Patient Selection Criteria

Patient population in our study included patients of 17 years of age or older with maxillary transverse deficiency of at least 5mm and posterior crossbite. All subjects were treated by either Dresden expander or Moon expander to address their maxillary transverse deficiency. All included patients had pre-expansion and post-expansion records taken, including Cone Beam Computed Tomography (CBCT), intraoral photos, and intraoral scans. Post-expansion records were taken shortly (within a month) after maxillary expansion was completed.

3.2.2 Tooth Selection Criteria

For this study, maxillary first premolars, second premolars, and first molars (Teeth # 1.6, 1.5, 1.4, 2.4, 2.5, and 2.6) were analyzed. The following were excluded from our analysis: dental implants, severely rotated teeth with the buccal surface that was pointing to the proximal surface of the neighbouring teeth, and teeth that were lingually positioned behind another tooth. Dental implants were excluded because they are osseointegrated and are not expected to move during orthodontic treatment. Also, the buccal surface of severely rotated or malpositioned teeth would not be in line with the buccal bone and gingival surfaces, thereby parameters of interest would not be possible to be measured without skewing the results.

3.3 Experimental design

For each patient, two sets of records were taken; one before starting treatment (T_1) and one after the maxillary expansion was completed (T_2) and any size of diastema formed between maxillary central incisors. The following records were taken for each patient at T_1 and T_2: diagnostic exams and charting, intraoral and extra-oral photos, Cone Beam Computed Tomography (CBCT), and Intraoral scans using an intraoral scanner. These data were analyzed to assess osseous and gingival changes, as well the risk for further gingival recession. Figure 3.1 visualizes experimental design for this study.

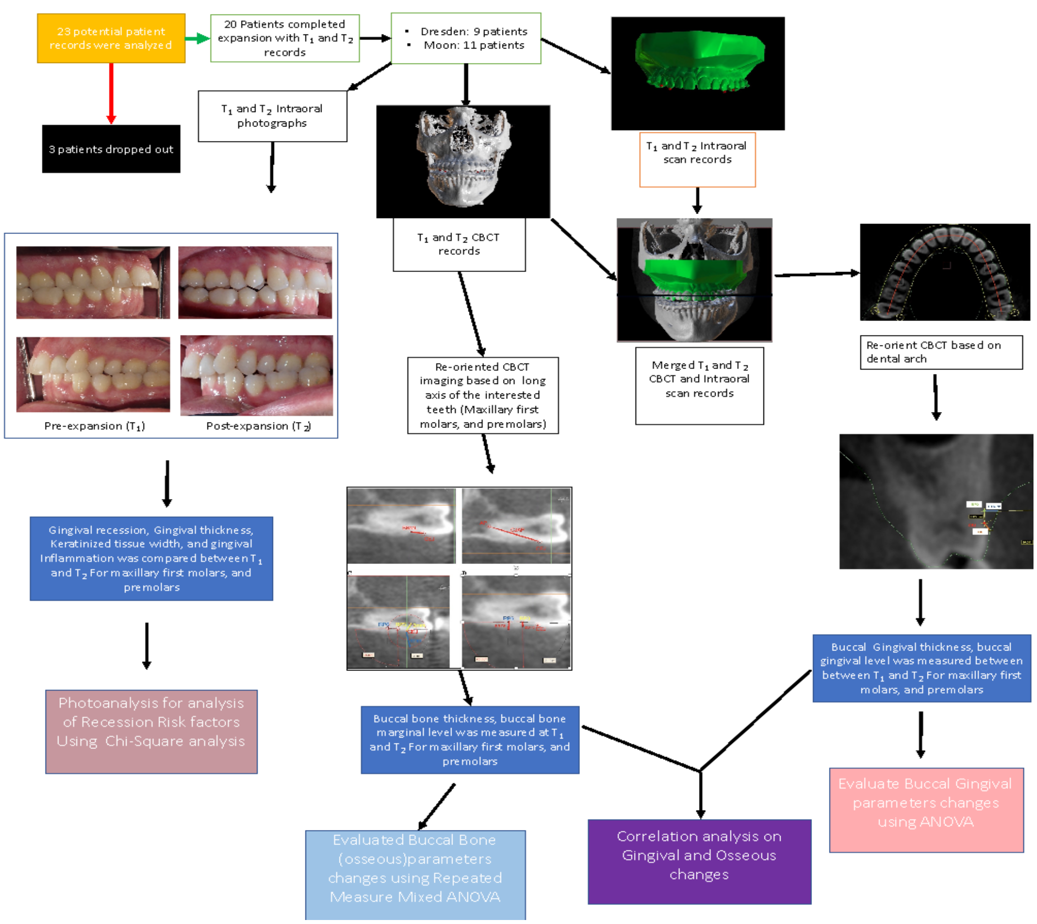


Figure 3.1 Experimental design

3.3.1 Dresden appliance and insertion protocol

Patients in group A received the Dresden appliance, which consisted of two miniscrews located 9 mm away from the mid-palatal suture, between maxillary second premolars and first molars. Appliances were fabricated by one laboratory technician at the University of Alberta, using model casts that were taken from each patient. A Dresden expander was placed in the patient's mouth by the orthodontist. To hold the expander in place, one miniscrew (9-11 mm in length) was inserted on each side of the palatal alveolar bone (total of 2 miniscrews) between the second premolars and first molars using local anesthetic (2% lidocaine, 1 carpule, 1:100,000 epinephrine).

3.3.2 Moon appliance and insertion protocol

Patients in group B received Moon appliance. Appliances were fabricated by the same laboratory technician at the University of Alberta, using model casts that were taken from each patient. Moon expander had bands on the maxillary first molars and the appliances were inserted in the patient's mouth by the same orthodontist and cemented to maxillary first molars using "reliance ultra-band-lok®" adhesive. The miniscrews for the Moon expanders were 11-13 mm long. Two Miniscrews were inserted on each side of the mid-palatal suture (total of four miniscrews) using local anesthetic (2% lidocaine, 1 carpule, 1:100,000 epinephrine).

3.3.3 Appliance expansion protocol

For the Dresden appliance, the activation protocol was one turn per day, which resulted in 0.25 mm maxillary expansion per day. For the Moon expander, the activation protocol was two turns per day, which resulted in 0.3 mm maxillary expansion per day.

During the first appointment, the Moon expander or the Dresden appliance were inserted, and brackets were placed on the mandibular teeth. Patients practiced how to do the turns based on the instructions given to them that day. Each patient had chlorohexidine rinse (0.12%) for 2 minutes prior to placement of the miniscrews. Both treatment groups continued to turn the appliances until their maxillary transverse deficiencies were resolved and palatal cusps of maxillary first molars occluded with the buccal cusps of mandibular first molars, according to McNamara's protocol as described by Bell.[54] Once a minimum of 5-10 mm of total expansion was achieved for each patient and diastema formed between maxillary central incisors, a second set of records were taken, and full fixed appliances were placed on maxillary teeth. To maintain the stability of the expansion and prevent any relapse, expanders were kept inactive in the patient's mouth for six months. Figure 3.2 demonstrates the designs of the Dresden and the Moon appliances.

A

B

Figure 3.2 Designs of the MARPE appliances used in the study.

A) The Dresden appliance B) The Moon appliance

3.3.4 Data acquisition

All CBCT scans were taken by a trained radiologist at the University of Alberta. I-CAT New generation machine was used to take large field of view CBCT scans (16 x 13.3 cm, 120 kVp, voxel size 0.30 mm, 18.54 mAS, and 8.9 seconds), where patients were instructed to keep their tongue on the roof of their mouth, avoid swallowing, and stay in maximum intercuspation. The patient's head was positioned so that it was parallel to the Frankfort horizontal plane. CBCT scans were stored in DICOM files and were analyzed using MIMICS ®and BlueSkyPlan ®software (version 4.7.5, BlueskyBio, USA).

Intraoral scans were taken by one trained dental assistant. The scans of the maxillary and mandibular arches were taken using iTero Element ® scanner at T_1 and T_2 time points. STL output was imported into and analyzed with BlueSkyPlan® software.

Intraoral photos (frontal, right and left lateral photographs) were also taken at T_1 and T_2 time points by one trained dental assistant using Canon G12 ® camera and intraoral mirrors. These photos were uploaded into Dolphin Imaging. Lateral photos were used for the photo analysis part of this study.

3.4 Method used for measurement of the buccal bone variables

The protocol for our analysis was adapted from Digregorio et al.[55] Patients' CBCT export data (DICOM files), which had been previously anonymized by removing all demographic data, were utilized. These files were then imported into MIMICS software (Version 19.0, Materialise, Belgium) for analysis of the buccal bone variables. CBCT data files included T_1 (pre-expansion) and T_2 (post-expansion) data points. Maxillary first premolars, maxillary second premolars, and maxillary first molars were analyzed for each case. CBCT data was analyzed using the “Bone Scale” Brightness/contrast preset in MIMICS software.

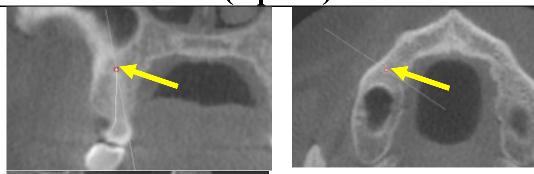
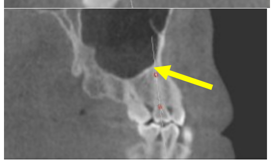
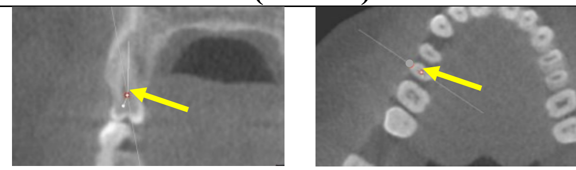
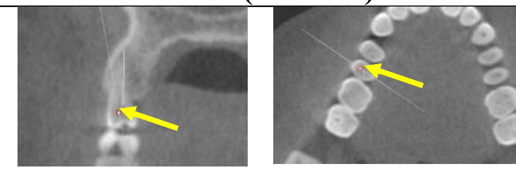
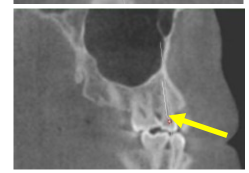
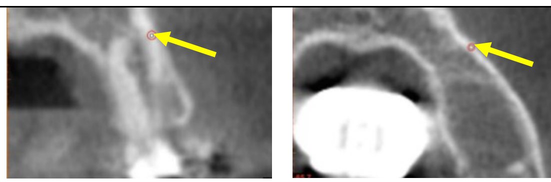
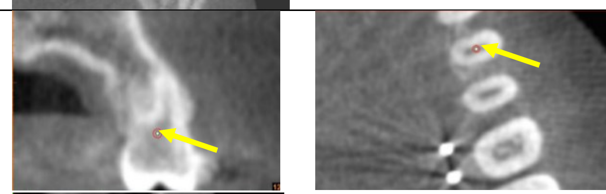
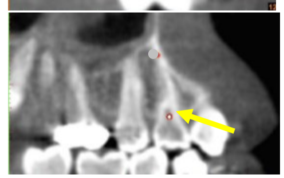
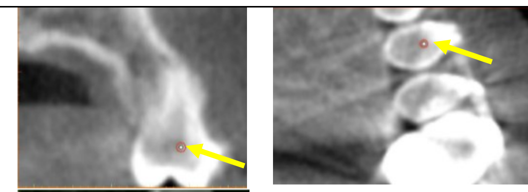
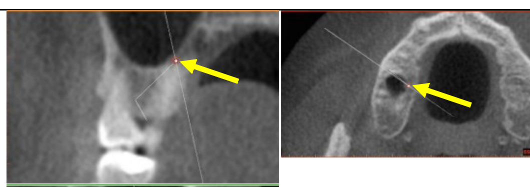
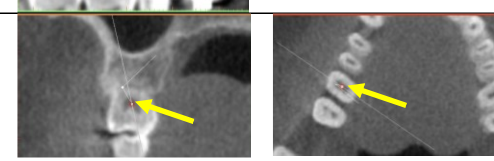
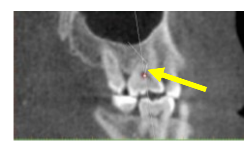
3.4.1 Reorientation of the CBCT Scans prior to data measurement

To ensure that the data collection is not affected by the patient’s head position and the orientation of the teeth, specific landmarks were used on the analyzed teeth to reorient the viewing plane on the CBCT scans. This reorientation was repeated for each tooth that was analyzed.

The protocol for reorientation of viewing planes is as follows; three landmarks (shown in Table 3.1) were used to create an orientation plane. The selection of the landmarks was based on the root configuration of the analyzed tooth to create a plane that mesiodistally bisected the buccal roots. For the maxillary molars, the mesiobuccal roots were analyzed.

In cases of root dilacerations, it was possible that the constructed orientation plane would not bisect the root through the mid-buccal aspect. In such scenarios, the orientation plane was manually adjusted so that it would pass through the mid-buccal aspect of the root and was in line with the long axis of the crown. Once the reorientation plane was established, the re-slice function of the software was utilized to reorient the view using the constructed plane, and to perform linear measurements.

Table 3.1 Landmarks used for re-orientation of the CBCT scans.

Root Configuration	First Landmark (Apical)	Second Landmark (Middle)	Third Landmark (Coronal)
1 root	  **Apex of the root**	  **Middle of the pulpal canal at the level of interproximal bone**	  **Buccal pulp-horn**
2 roots	  **Apex of the buccal root**	  **Middle of the pulpal canal at the level of interproximal bone**	  **Buccal pulp-horn**
3 roots	  **Apex of the palatal root**	  **Most coronal aspect of buccal bifurcation**	  **Middle of pulp chamber**

Coronal (top left), Sagittal (bottom left) and Axial (top right) views have been shown for each landmark selected.

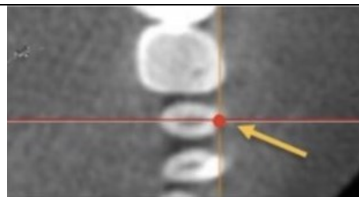
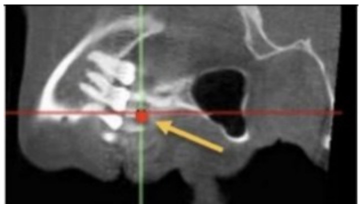
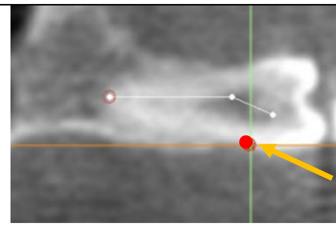
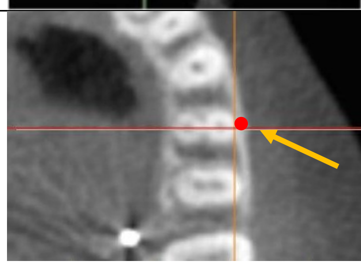
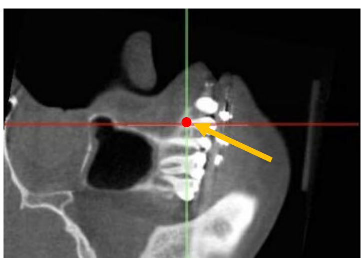
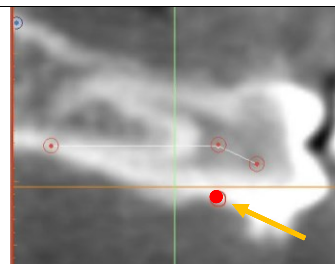
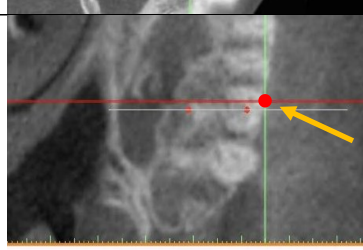
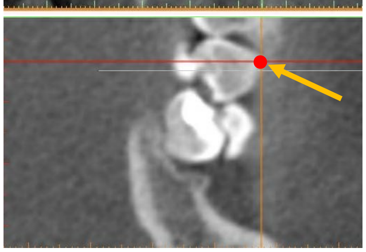
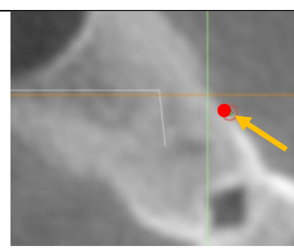
3.4.2 Landmarks used for linear measurement of the buccal bone variables

After the CBCT scan was reoriented, the location of the Cemento-Enamel junction (CEJ) was located by detecting a sharp decrease in radiodensity on the tooth surface (Table 3.2). This location served as a reference coordinate for measurements. Then, the distance between the CEJ and the buccal root contact with bone was measured. This served as the Buccal Bone Marginal Level (BBML).

Subsequently, two circles of 3.0mm and 6.0mm radius were drawn. The center of these circles was placed on the marked CEJ. The intersection of these circles to the root surface was marked as root point 3 (RP3) and root point 6 (RP6) points. Using a digital protractor, perpendicular (90.0 degrees) lines were drawn to the root surface passing through RP3 and RP6 points. The intersection of these lines with the buccal bone was marked again. After that, the thickness of the buccal bone was measured as the distance between these points on the buccal bone and RP3 and RP6. These variables were denoted as Buccal Bone Thickness 3 (BBT3) and Buccal Bone Thickness 6 (BBT6) for buccal bone thickness at RP3 and RP6, respectively.

Distance from CEJ to the apex of the root was also measured as CJAP. This distance was used as a reference to locate the CEJ position later if the orthodontic band around the tooth obstructed the CEJ at the T_2 time point. This method of measurement of buccal bone dimensional parameters is visualized in Figure 3.3. All measurements were repeated three times and the average was used in the analysis.

Table 3.2 Position of CEJ on the analyzed root

Root Configuration	CEJ position	
1 root	 	 **Mid facial aspect of the buccal root**
2 roots	 	 **Mid facial aspect of the buccal root**
3 roots	 	 **Mid facial aspect of the mesiobuccal root**

Axial (top left), Sagittal (bottom left) and Coronal (top right) views of the identified CEJ.

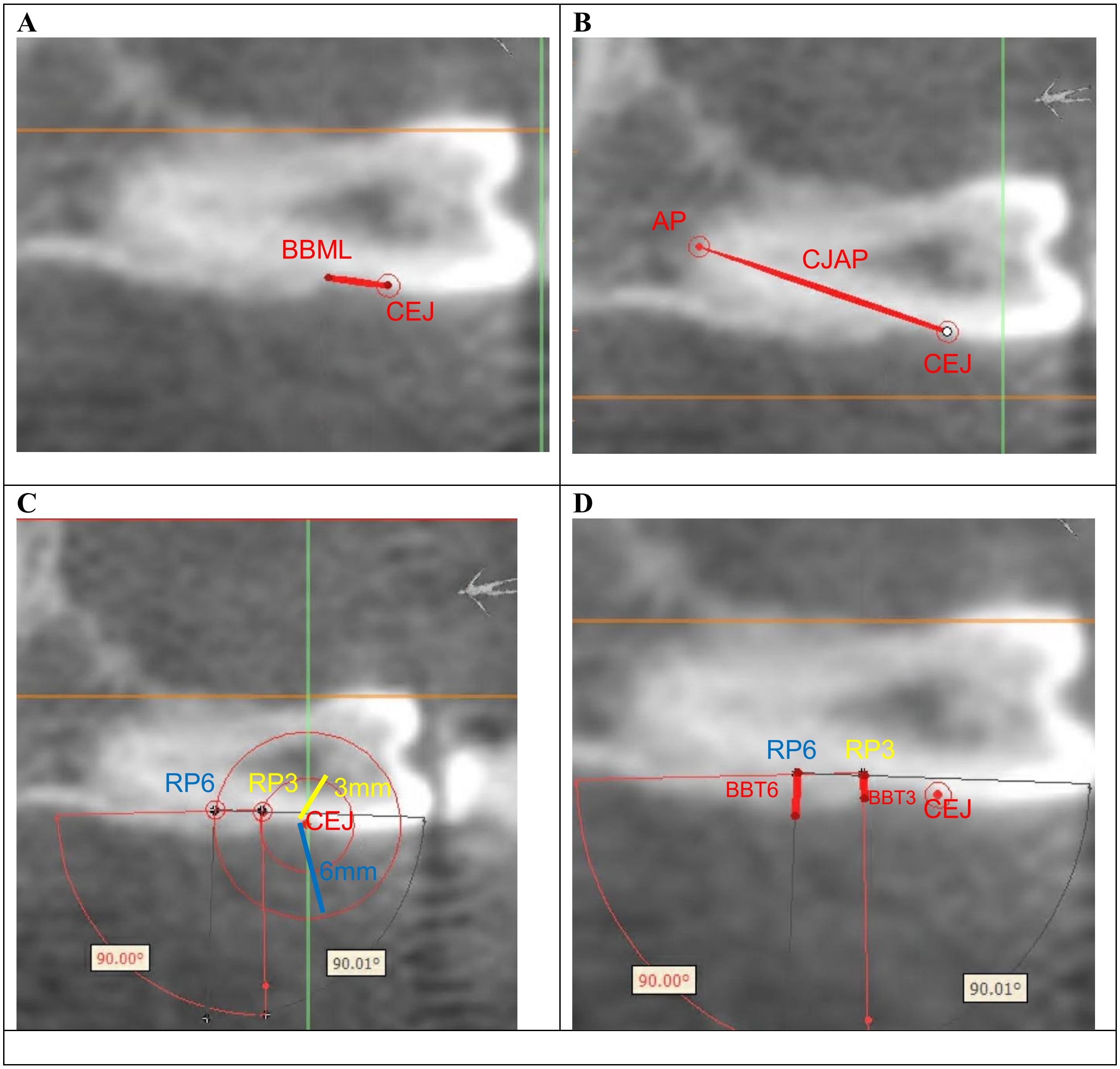


Figure 3.3 CBCT Analysis of buccal bone variable.

A) Buccal bone marginal level (BBML) is measured by measuring the distance between the Cemento-Enamel junction (CEJ) and most coronal aspect of buccal bone on root surface. B) CJAP is measured by taking the distance from Apex (AP) of the root to the CEJ. **C)** Circles of radius 3.0mm and 6.0mm are drown with centre located on CEJ. Intersection of these circles with the root surface are denoted as RP3 and RP6. **D)** Buccal Bone Thickness at 6mm (BBT6) and 3mm (BBT3) from CEJ are determined by drawing perpendicular lines to root surface at RP3 and RP6 and measuring the thickness of the buccal bone

3.4.3 Method used for linear measurement of the gingival variables

The anonymized CBCT exports (DICOM files) at T_1 and T_2 were imported to BlueskyPlan (version 4.7.5) for analysis. Corresponding Intraoral scan exports (STL files) at T_1 and T_2 time points were also imported into the software to merge the data. Brightness and Contrast settings were left as Default settings in BlueSkyPlan.

3.4.4 Alignment of intraoral scan models with the CBCT scan models

Using the automatic alignment workflow of the software, the surface of the maxillary teeth in the intraoral scan was aligned with the surface of the maxillary teeth in the CBCT scan. In case of poor alignment, 3-4 points that were clearly visible on both scans were used to perform this alignment manually. This methodology is shown in Figure 3.4.

Such a combination of data would combine dental and osseous data from the CBCT files with dental and gingival surface data from the intraoral scan. A similar methodology was previously explained by Kim et al.[56] and Couso-Queiruga et al..[57]

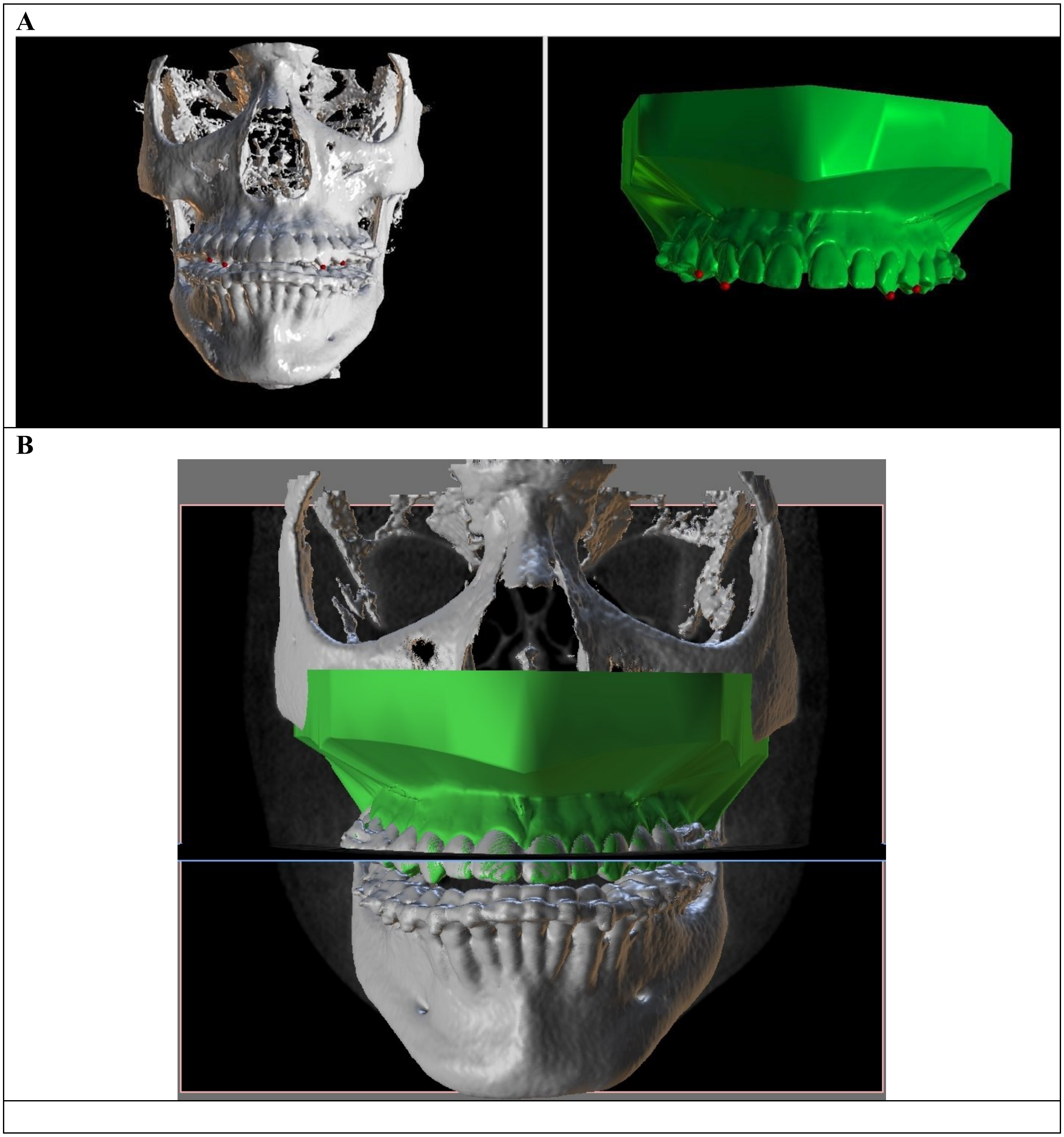


Figure 3.4 Super imposition of Intraoral scan data on CBCT.

A) 4 fiducial marking points (red spheres) were selected on CBCT data (grey). Corresponding points on the intraoral scan (green) were also selected. **B)** Using the matched points, intraoral scan surface (green) is successfully superimposed on the CBCT surface data (grey)

3.4.5 Landmarks used for the measurement of buccal gingival variables

To perform measurements of the gingival variables, a panoramic curve was drawn using the software at the level of CEJ of the teeth ensuring that it would pass through the center of all of the maxillary teeth in the axial view. Then, the cross-sectional projection marker was adjusted such that it would bisect the buccal root to be analyzed in teeth of interest and pass through the middle of the tooth (as shown in Figure 3.5).

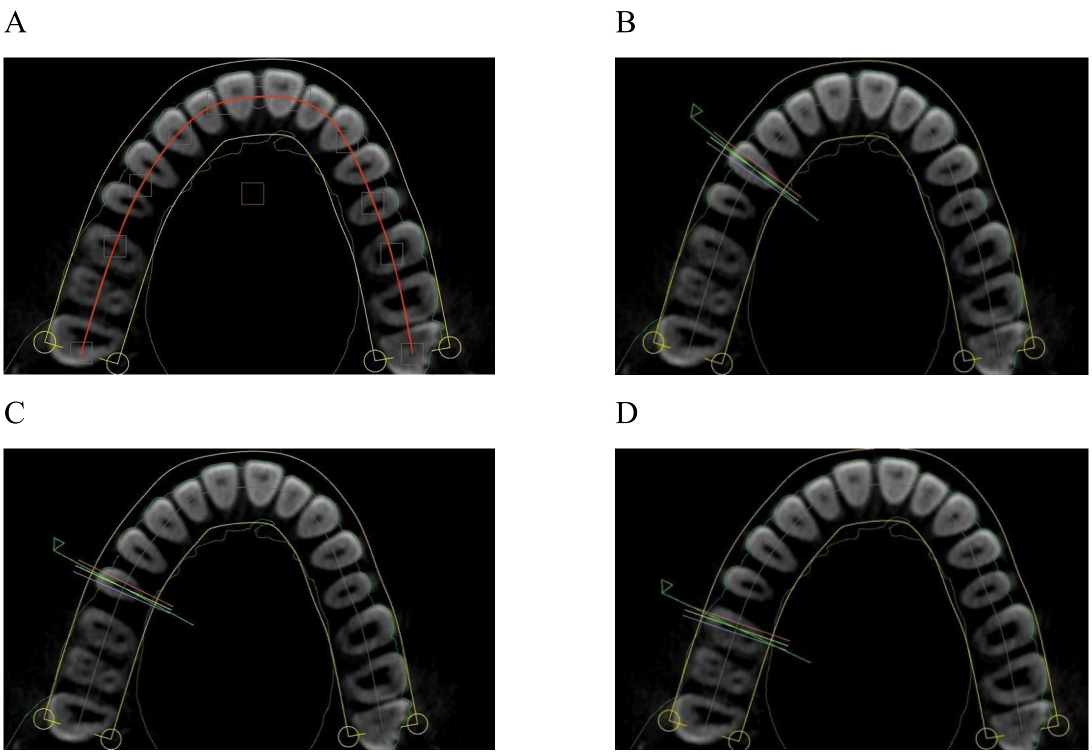


Figure 3.5 Dental arch and cross-section selection.

A) A dental arch (red outline) was drawn at the level of CEJ such that it would pass through the middle of all posterior teeth in the maxillary dental arch. **B)** Using the fine adjustable Cross-section selection tool (green line with arrow) the cross-section was further refined so that it would pass through the mid-buccal aspect of the first premolars. **C)** Same technique was repeated for the buccal root of the second premolars. **D)** This cross-section selection tool was further adjusted such that it would bisect the mesiobuccal root of the first molars.

Using the cross-sectional view, CEJ was located for use as a landmark for measuring gingival variables of interest. After that, a point on the tooth surface which intercepted the gingival surface most coronally was marked. The distance between this point and the CEJ was measured. If this position was apical to CEJ, a positive number was given and if this position was coronal to CEJ, a negative number was given. This determined the gingival level (GL).

From the CEJ, a 2mm apical position on the root surface was also measured. Using a digital protractor, a perpendicular (90 degrees) line relative to the root surface at this point to the surface of overlaying gingiva was measured. This measurement was denoted as GTRP2. All measurements were repeated three times and the average was the used in analysis. Figure 3.6 visualizes these measurements below.

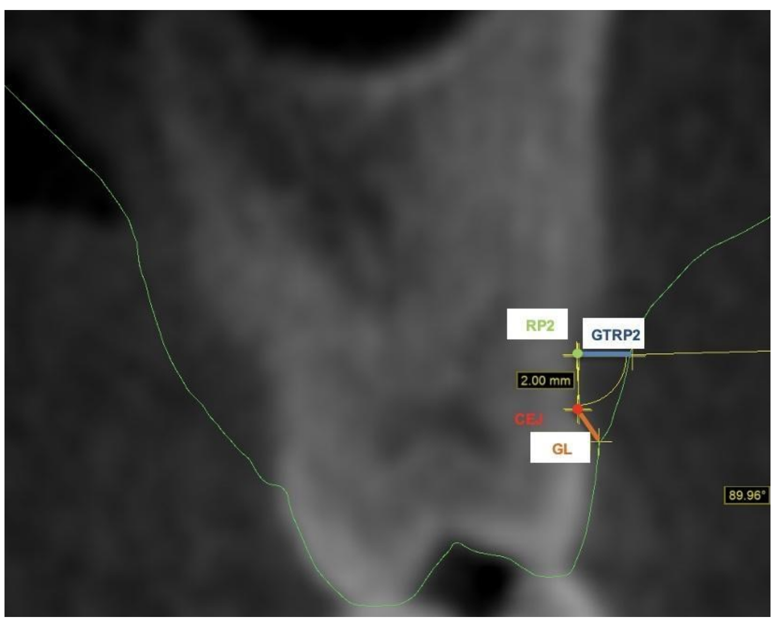


Figure 3.6 CBCT analysis of Gingival dimension parameters.

Gingival level (GL) was measured by measuring the distance between the point of contact of the gingival surface (green) with tooth structure. RP2 was a root surface 2.0mm apical to CEJ. A perpendicular line from the root surface at RP2 and crossing the gingival surface was drawn. GTRP2 was measured by measuring the distance from the gingival surface to RP2 on this perpendicular line.

3.5 Photo-analysis of the intraoral photographs

To account for intraoral variables that may influence or be affected by the orthodontic expansion, lateral intraoral photographs taken at T_1 (pre-expansion) and T_2 (post-expansion) were analyzed. Keratinized gingival width, gingival inflammation, gingival thickness, and gingival recession were analyzed based on the photographs. The presence of these factors was individually assessed for each of the assessed teeth, and ordinal scores were given (as tabulated in Table 3.3). These factors were separately assessed by two trained investigators (MG and AT). Disagreements on scoring were resolved by consensus.

Figure 3.7 includes a sample set of intraoral photographs taken at T_1 and T_2 time points. This analysis protocol was adapted from Kobewka, 2021,[58] whose methodology was adapted from Root Coverage esthetic Score (RES) by Cairo et al.,[59] The Before and After Scoring System (BASS) by Kerner,[60] and Pink Esthetic Score (PES) by Fürhauser et al..[61]

Table 3.3 Photo-analysis scored factors

	Score		
Parameter	0	1	2
Gingival recession (GR)	FGM Follows CEJ	FGM is apical to CEJ	FGM is apical to CEJ and has worsened from the initial recession
Keratinized tissue width (KTW)	FGM - MGJ ≥ 2mm	FGM - MGJ < 2mm	N/A
Inflammation (Inf)	colour of marginal tissue is uniform from the marginal gingiva to the vestibule, lack of swelling	colour of marginal tissue varies from color more apical (red), swollen, edematous	N/A
Keratinized tissue thickness (KTT)	Tissue appears to be thick (>1mm)	Tissue appears to be thin (<1mm)	N/A

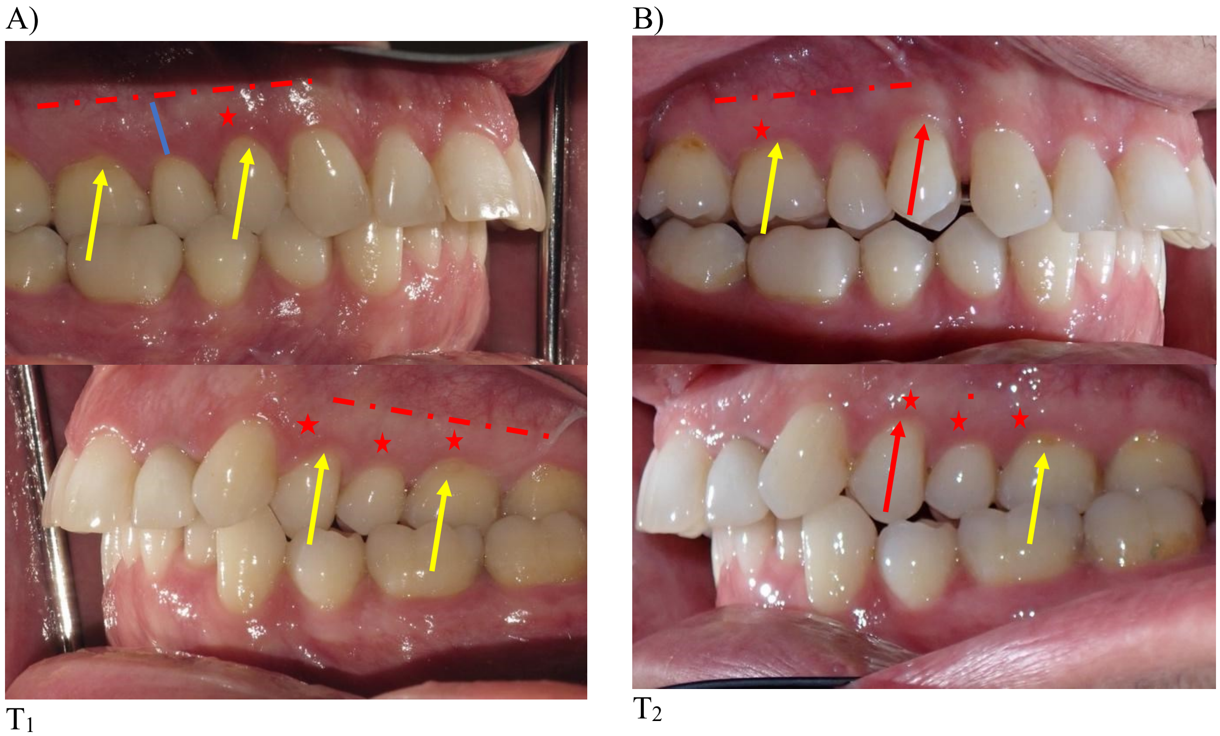


Figure 3.7 Sample lateral intraoral photographs of the mouth.

Dashed red line indicates mucogingival junction (MGJ). Gingiva below this line is keratinized and the width of this keratinization determined from free gingival margin to MGJ is the basis for scoring KTW parameter. A) Photographs taken at T_1 (pre-expansion) timepoint. B) Photographs taken at T_2 (post-expansion) timepoint. Point of inflammation noted on 14B. Yellow arrows indicate recession (score of 1). Red arrow indicates worsened recession (score 2). Red stars indicate presence of inflammation at the gingival margin. Tissue here appears to be thick.

3.6 Statistical Analysis

The statistical analysis was performed using IBM SPSS version 28.0.1.1 for Mac (IBM Armonk, N.Y., USA) and the significance level was set as $\alpha = 0.05$. Hypothesis statements are listed in Table A3.1(Appendix) detailed description of how each research question was statistically analyzed (as explained in Section 1.5.1) is outlined in Table A3.2 of the appendix section.

3.6.1 Intra-examiner reliability testing and measurement error

Intra-class correlation coefficient (ICC) was performed using ten CBCT/STL data sets that were randomly selected from the patient pool. Gingival and osseous outcome variables (BBT3, BBT6, BBML, GTRP2, and GL) were measured three times. There was a one-week interval between each set of measurements and the examiner was blinded to previous measurements. Data were analyzed using a two-way random model, absolute agreement and average measures were used. For each variable, measurement error was also calculated by averaging the absolute differences between the measurements.

3.6.2 Response and factor variables

Osseous and gingival changes:

For analysis of the osseous and gingival changes, the response variables are as follows: BBT3 (mm), BBT6 (mm), BBML (mm), GTRP2 (mm), and GL (mm). There are two factor variables each with two levels: 1) Appliance: Dresden expander and Moon expander and, 2) Time: T_1 (pre-expansion) and T_2 (post-expansion). Appliance is a between-subject factor, while time is a within-subject factor.

Photo-analysis:

For photo-analysis, the response variables were changes in gingival recession (GR), keratinized tissue width (KTW), inflammation (Inf), and keratinized tissue thickness (KTT) (previously explained in section 3.4). These changes were computed by subtracting discrete values of these parameters at T_2 from their values at T_1:

ΔKTT: KTT_{T2}-KTT_{T1}

ΔKTW: KTW_{T2}-KTW_{T1}

ΔInf: Inf_{T2}-Inf_{T1}

ΔGR: GR_{T2}-GR_{T1}

Computed variables had three ordinal levels: -1(improved), 0 (no change), and 1(worsened).

3.6.3 One-way repeated measures mixed ANOVA tests: Osseous and Gingival parameters

One-way repeated measures mixed ANOVA tests were conducted to determine if there are any differences in the BBT3, BBT6, BBML, GTRP2, and GL between the two appliance groups (Moon, Dresden) from pre-expansion (T_1) to post-expansion (T_2) time points. These parameters were analyzed separately for maxillary first premolars, second premolars, and first molars.

Once ANOVA tests were performed, Bonferroni correction was used by means of multiplication of p-values by the number of ANOVA tests conducted (30) to reduce type I error. If the adjusted p-value was more than 1.00, it was designated with a value of 1.00.

3.6.4 Correlation Analysis: Osseous and Gingival parameters

Difference (Δ) between osseous (BBT3, BBT6, BBML) and gingival parameters (GL, GTRP2) from T_1 to T_2 for the two appliances in maxillary first molars, first premolars and second premolars were calculated.

Normality testing was performed to help determine the type of correlation statistics to be performed. Depending on the result of normality test, Pearson Correlation could be used on normally distributed data and Spearman correlation could be used on non-normally distributed data. These correlation statistics were used to determine the correlation between ΔGL- ΔBBT3, ΔGL- ΔBBT6,ΔGL- ΔBBML, ΔGTRP2- ΔBBT3, ΔGTRP2- ΔBBT6, ΔGTRP2- ΔBBML in each tooth group for both appliance groups. Bonferroni correction of 36 (for the total number of comparisons) was performed to reduce type I error. If the adjusted p-value was more than 1.00, it was designated with a value of 1.00.

3.6.5 Statistical analysis of Photo-analysis

Distribution of photo-analysis parameters (ΔGR, ΔKTT, ΔKTW, ΔInf) as listed in section 3.5.2 with categories of worsened (1), no change (0), and improved (-1) were analyzed using Chi-Square analysis between the two appliances (Dresden and Moon Expanders). Bonferroni correction was used by means of multiplication of p-values by the number of Chi-Square tests conducted (12) to reduce type I error. If the adjusted p-value was more than 1.00, it was designated with a value of 1.0.

Chapter 4 - Results

4.1 Results

4.1.1 Subject Demographics

Of the twenty-three adult patients (17 years or older) who had been allocated to receive maxillary expansion with either Dresden or Moon appliances, three patients did not complete the expansion (or did not have adequate records) and were not further analyzed. Of the remaining twenty patients who completed maxillary expansion, nine patients were expanded with the Dresden appliance and were designated as group A. The remaining eleven patients were expanded using the Moon expander and were designated as group B. Subjects' demographic characteristics are summarized in Table 4.1.

Table 4.1 Subjects' demographics

Appliance	n	Age range	Mean Age ± SD	# of Females	# of Males
Dresden	9	17.0-47.2	27.3 ±10.3	3	6
Moon	11	17.0-40.3	25.8 ± 8.2	7	4

4.2 Intra examiner Correlation Coefficient (ICC): Osseous and Gingival Parameters

The results for Intra examiner Correlation Coefficient (ICC) for Osseous parameters (BBT3, BBT6, BBML) and gingival parameters (GL and GTRP2) for maxillary first molars, first premolars, and second premolars is demonstrated in Table 4.2. The ICC values were evaluated based on ICC guidelines described by Portney and Watkins.[62] Based on these guidelines, values of ICC≥0.90 indicate excellent agreement between measurements, 0.75<ICC≤ 0.89 indicate good agreement between the measurements, 0.74≥ICC≥0.51 indicate moderate agreement, and ICC ≤0.50 indicate poor agreement between measurements. In this analysis, the ICC values obtained for all parameters were above >0.99, which indicates excellent agreement between measurements.

The lowest 95% confidence interval was for the BBT6 parameter in the first molars with a value of 0.979, and the highest correlation coefficient was 1.000 for BBML for the first premolars and GL for each tooth-type.

Table 4.2 Intra-examiner reliability (Intra-class correlation coefficient (ICC)) using average measures of three measurements taken from 10 randomly selected patients

Parameter	Tooth-type (maxillary)	Intraclass Correlation (Average Measures)	95% Confidence Interval (Lower Bound)	95% confidence Interval (Upper Bound)
BBT3	First Premolars	0.997	0.991	0.999
	Second Premolars	0.998	0.993	0.999
	First Molars	0.997	0.993	0.999
BBT6	First Premolars	0.993	0.980	0.998
	Second Premolars	0.994	0.983	0.998
	First Molars	0.993	0.979	0.998
BBML	First Premolars	1.000	0.999	1.000
	Second Premolars	0.997	0.992	0.999
	First Molars	0.999	0.996	1.000
GL	First Premolars	0.999	0.998	1.000
	Second Premolars	1.000	0.999	1.000
	First Molars	1.000	0.999	1.000
GTRP2	First Premolars	0.996	0.989	0.999
	Second Premolars	0.998	0.993	0.999
	First Molars	0.996	0.989	0.999

BBT3: Buccal bone thickness 3mm from CEJ, BBT6: Buccal Bone Thickness 6mm from CEJ, BBML: Buccal bone marginal level relative to CEJ, GL: Gingival level relative to CEJ, GTRP2: Gingival thickness 2mm from CEJ

4.3 Measurement error: Osseous and Gingival Parameters

In addition to ICC determination, measurement errors for the osseous and gingival parameters were also computed for 10 randomly selected patients. The highest average measurement errors for BBT3, BBT6, BBML, GL and GTRP2 observed to be 0.12mm around second premolars, 0.07mm around second premolars, 0.12mm around second premolars, 0.07mm around first molars, and 0.06mm around first molars, respectively. Table 4.3 summarizes the measurement errors for all the osseous and gingival parameters around the analyzed teeth.

Table 4.3 Measurement error from three measurements trials (Ten randomly selected patients)

Tooth-type (Maxillary)	Parameter	Mean	SD	Min	Max
Max First Premolars	BBT3 (mm)	0.06	0.03	0.02	0.12
	BBT6 (mm)	0.06	0.04	0.01	0.14
	BBML (mm)	0.06	0.04	0.01	0.11
	GL (mm)	0.04	0.04	0.00	0.10
	GTRP2 (mm)	0.04	0.02	0.02	0.07
Max Second Premolars	BBT3 (mm)	0.08	0.09	0.02	0.32
	BBT6 (mm)	0.07	0.06	0.00	0.16
	BBML (mm)	0.12	0.11	0.00	0.29
	GL (mm)	0.04	0.03	0.00	0.10
	GTRP2 (mm)	0.04	0.03	0.01	0.11
Max First molars	BBT3 (mm)	0.09	0.07	0.01	0.20
	BBT6 (mm)	0.06	0.05	0.01	0.15
	BBML (mm)	0.10	0.06	0.02	0.22
	GL (mm)	0.07	0.05	0.01	0.13
	GTRP2 (mm)	0.06	0.05	0.01	0.14

BBT3: Buccal bone thickness 3mm from CEJ, BBT6: Buccal Bone Thickness 6mm from CEJ, BBML: Buccal bone marginal level relative to CEJ, GL: Gingival level relative to CEJ, GTRP2: Gingival thickness 2mm from CEJ

4.4 Descriptive Statistics for Osseous and Gingival Parameters

Table A4.1 (Appendix) summarizes the descriptive statistics at T_1 and T_2 for osseous and gingival parameters for maxillary first premolars, second premolars, and first molars for the Dresden and Moon appliances.

Descriptive statistics showed that from T_1 to T_2 for both the Dresden and the Moon appliances, the mean value for BBT6 and BBT3 decreased for all teeth, indicating that the buccal bones got thinner after maxillary expansion. The mean value for BBML increased, indicating that the buccal bone levels were apically repositioned after maxillary expansion.

The buccal gingival thickness at 2 mm from CEJ (GTRP2) had a mean decrease for all teeth except for maxillary first premolars in the Dresden expander group. Gingival level (GL) also increased for all teeth, except for the maxillary second premolars in the Moon expander group, for which this value decreased by 0.11mm (SD 0.28mm).

4.5 Results of repeated measure mixed ANOVA test: Osseous and Gingival Parameters

Assumption testing for the use of ANOVA as a statistical method to analyze osseous and gingival parameters was performed. These assumptions were determined to be met as tabulated in Table A4.2 (Appendix). The result of within-subject effects for BBT3, BBT6, BBML, GL, and GTRP2 for maxillary first and second premolars and first molars are shown in Table A4.5 (Appendix).

The adjusted p-values for PrePost (time) analysis of most osseous parameter changes (except for BBT6 in first molars) were $p>0.05$. Therefore, changes from T_1 to T_2 in BBT3, and BBML for all three tooth-types, and changes in BBT6 for maxillary first and second premolars were not statistically significant after maxillary expansion with either appliance.

On the other hand, the adjusted p-value for BBT6 for the maxillary first molars was statistically significant ($p<0.03$). Therefore, results show that there is a difference in BBT6 for the first molars from T_1 to T_2, regardless of the type of appliance used. To test the main effects, a pairwise comparison test using Bonferroni correction was performed and indicated that there was a 0.31 mm reduction in BBT6 value from T_1 to T_2 (Table A4.6, Appendix). In other words, maxillary expansion with either appliance resulted in a mean reduction of 0.31mm in buccal bone thickness, 6 mm from CEJ in the maxillary first molars. As such, the alternative hypothesis (H_a) #1 (Table A3.1, Appendix) was accepted.

In addition, analysis of GL and GTRP2 for maxillary first premolars, second premolars, and first molars with PrePost(time) as the within-subject had a p-value >0.05. Therefore, regardless of the appliance type used, gingival levels (GL) and gingival thickness (GTRP2) parameters did not experience a statistically significant change after maxillary expansion (from T_1 to T_2) for any of the tooth types analyzed (Null hypothesis (H_0) #3 accepted, Table A3.1, Appendix)

Moreover, PrePost*ApplianceType interactions provided no statistically significant results (p-values were >0.05) for any of the dependent variables. In other words, From T_1 to T_2, appliance type did not influence changes in parameters BBT3, BBT6, BBML, GL and GTRP2 for any of the tooth types analyzed. Thus, null hypothesis (H_0) #2 and # 4 were accepted (Table A3.1, Appendix).

4.6 Correlation of Osseous and Gingival parameters

4.6.1 Selection of correlation statistics

The differences between the T_2 and T_1 values for BBT6, BBT3, BBML, GL, and GTRP2 for the three tooth types were determined for both appliance groups. Shapiro Wilk test (Table A4.7, Appendix) showed that these parameters were mostly not normally distributed. Therefore, Spearman correlation statistic was chosen to correlate gingival and osseous parameter changes as the data was continuous, and not normally distributed.

4.6.2 Correlation statistics between Gingival Changes and Osseous Changes

Spearman's Rho correlation analysis was performed between gingival and osseous parameter changes (Table A4.8, Appendix). After significance levels were adjusted by Bonferroni correction of 36 (number of comparisons), the only significant correlation was found to be the change in gingival thickness parameters (ΔGRTP2) correlation with buccal bone thickness, 3 mm from CEJ (ΔBBT3) around the maxillary second premolars in the Dresden expander group. The Rho value of this correlation was 0.918 with an adjusted p-value of <0.035, indicating a statistically significant and very strong correlation.

The scatter plot of ΔGRTP2-ΔBBT3 around second premolars in the Dresden expander group is shown in Figure A4.4 (Appendix). This scatter plot indicates a positive monotonic relationship between these values and confirms the correlation found. In other words, after maxillary expansion in the Dresden expander group, the changes in gingival thickness around second premolars correlate with buccal bone thickness changes, 3mm from CEJ. Since this correlation was found to be significant, the null hypothesis was rejected (hypothesis #5, Table A3.1, Appendix) and the alternative hypothesis was accepted. No other gingival and osseous changes were found to be correlated around the teeth and treatment groups analyzed.

4.7 Analysis of risk factors according to photo-analysis.

The changes in keratinized tissue thickness (KTT), keratinized tissue width (KTW), inflammation (Inf), and gingival recession (GR) scores from T_1 to T_2 for maxillary first premolars, second premolars, and first molars were calculated and organized to values of -1(improved), 0 (no change), and 1(worsened). Table A4.9 (Appendix) demonstrates the crosstabulation of the frequency of this change in variables assessed among the appliance groups.

To assess whether the ΔKTT, ΔKTW, ΔInf, and ΔGR are different among the two appliance groups, a Chi-square analysis was performed (Table A4.10, Appendix). Since ΔKTT and ΔKTW had a value of 0 (unchanged) for both maxillary second premolars and first molars, and ΔKTT had a value of 0 (unchanged) for maxillary first premolars, no analysis was performed for these parameters in the said tooth groups. For other parameters, the p-value of the Chi-square analysis was adjusted by multiplying it with the number of tests (7) to the maximum value of 1.0. For most parameters, the expected value of cells was less than 5. Therefore, Fisher's Exact test value was evaluated. For ΔGR in maxillary second premolars, values in the cells were above 5. Therefore, Pearson Chi-Square Asymptotic value was used instead.

Since all the adjusted significance values were >0.05, the null hypothesis (hypothesis # 6, Table A3.1, Appendix) was accepted, and the alternative hypothesis was rejected. In other words, the incidence of risk factors such as gingival inflammation and gingival recession increased for all tooth-types in both appliance groups. However, the distribution of the development of these risk factors between the two MARPE appliances was not statistically significant ($p>0.05$). Keratinized tissue thickness and width parameters had minimal, if any, changes after maxillary expansion with either appliance in all tooth groups.

Chapter 5 - Discussion

5.1 Discussion

The aim of this study was to evaluate periodontal changes (including Osseous and gingival changes) after using miniscrew assisted rapid palatal expansion (MARPE) in adults. Two different MARPE appliances (Dresden expander and Moon expander) were utilized and teeth adjacent to these appliances (maxillary first premolars, second premolars and first molars) were analyzed.

The Osseous changes were evaluated by analyzing CBCT records taken at T_1 (pre-expansion) and T_2 (Post expansion). Gingival changes were determined after superimposing intraoral scans taken at the same time point over the CBCT data and measuring gingival parameters around the same teeth. The osseous parameters were measured using MIMICS software, while gingival parameters were measured using BlueSkyplan software.

Photo-analysis of intraoral photos were done by two examiners. Risk factors for further recession were scored and changes in these factors were compared between the two appliance groups. Previous studies on this topic have been limited and do not often include the same appliance types, population, or methodology of assessment. Therefore, caution should be taken when comparing the result of our study with existing literature.

5.1.1 Osseous parameter changes

In this study, the buccal bone thickness changes at 3mm from CEJ (BBT3) had a decreased mean value for both Dresden and Moon appliance groups after maxillary expansion. However, this change was not statistically significant for any of the tooth-types analyzed (molars and premolars). On the other hand, buccal bone thickness at 6mm from CEJ was determined to be statistically different from T_1 to T_2 in the first molars ($p<0.03$) with a mean reduction of 0.31mm, regardless of the type of appliance used. This change, however, was not significant for the first and second premolars. The reason why the change in BBT3 was not statistically significant for molars, while the change was significant for BBT6 could be because several molars had no existing buccal bone at 3mm from CEJ at T_1 and T_2 time points. Therefore, BBT3 values for those with no existing buccal bone were excluded from our analysis. This exclusion likely led to a lack of statistical power for changes in BBT3 and caused the reported p-value to be larger than the set al.pha.

The changes in BBT6 that were observed in our study are comparable to findings from the study conducted by Lim et al..[51] They reported a statistically significant mean reduction of 0.36 ±0.29 mm in buccal bone thickness around the maxillary first molars immediately after maxillary expansion with a type 3 appliance. In their study, the first premolars also experienced a statistically significant reduction of 0.52±0.38mm in buccal bone thickness, whereas our study showed no statistically significant changes around the first premolar area. In another pilot study conducted by Ngan et al.,[52] they evaluated buccal bone thickness after maxillary expansion with a type 3 MARPE appliance (Moon expander) in eight skeletally mature adult patients (2 females, and 6 males). Results showed that the mean buccal bone thickness around the mesiobuccal (MB) root of the maxillary right first molars was reduced by 0.6±0.46mm. However, no significant reduction was noted for the MB root of the left first molars. In the first premolars buccal bone thickness was determined to be statistically significant and reduced by 0.54±0.53mm and 0.68±0.70mm for the right and left sides, respectively.

In regard to buccal bone marginal levels, the study by Lim et al.[51] reported 0.74±0.93mm apical migration of alveolar bone at first molars, 2.27±2.99mm at first premolars, and 0.66±0.62mm at second premolars, immediately after maxillary expansion. In contrast, in our analysis, the buccal bone marginal levels were not statistically different in any of the tooth-types and appliance groups from T_1 to T_2.

Furthermore, the reduction of BBT6 values around maxillary first molars that was observed in our study could be attributed to the way the MARPE appliances exerted their forces to the palate. The moon expander utilized banded molars as anchoring teeth in addition to the miniscrews inserted in the palate to exert forces required for maxillary expansion. The Dresden appliance, on the other had, did not utilized orthodontic bands, but instead utilized miniscrews that were placed in between maxillary first molars and second premolars. The designs of these MARPE appliances could have led to thinning of buccal bone thickness around the MB root of the maxillary first molars because of the orthodontic buccal tooth movement or buccal inclination of the teeth. These type of tooth movements and inclination changes were observed after MARPE expansion in the study by Yi et al.,[63] who evaluated 19 subjects (15-29 years of age) after MARPE expansion. In this study, authors found that 55% the total maxillary expansion could be attributed to dental expansion, while bone and alveolar expansion accounted for 32% and 13% of the total changes at the first molar area. However, since these measurements were not part of our study, it is important not to directly compare the two studies.

5.1.2 Effect of the appliance type on osseous parameter changes:

In our analysis, appliance design had no statistically significant effect on changes observed after maxillary expansion for buccal bone thickness parameters (BBT3 and BBT6) and buccal bone marginal levels for any of the teeth groups analyzed. These results are different from the findings by Moon et al. (2020).[53] They compared the Moon expander (type III MARPE) in patients with a mean age of 19.2±5.9 years with a C-expander (type II MARPE) in patients with a mean age of 18.1±4.5 years. Their results indicated that different appliance designs could have different effects on the osseous dimensional changes. Compared to the C-expander group, the Moon expander group had approximately 1.48mm and 1.02mm more buccal bone height loss for the alright and left maxillary first molars, respectively. The Moon expander group also had 0.53mm and 0.47mm more buccal bone thickness reduction for the right and left maxillary first molars, respectively (compared to the C expander group).

Possible reasons for differences in results could be a smaller sample size in our study (n=20) compared to the study conducted by Moon et al. (n=48), which could have contributed to a lower statistical power in our results. Additionally, while both C-expander and Dresden appliances are type III MARPE appliances, they have significant differences in their designs. The C-expander has a total of four miniscrews; Two miniscrews are inserted between the canine and first premolars and two miniscrews are inserted between the first molars and second premolars on each side of the mid-palatal suture. On the other hand, the Dresden appliance has two miniscrews between second premolars and first molars that are inserted into the buccal alveolar bone. Such differences in design could lead to a different distribution of forces between the two appliances and result in different outcomes.

5.2 Gingival parameter changes

Gingival levels (GL) and gingival thickness parameter changes from T_1 to T_2 were not statistically significant for any of the tooth types and appliances analyzed ($p>0.005$). This indicates that within the timeframe of our study, gingival parameters around the maxillary first molars and first and second premolars were not affected by maxillary expansion. Previous studies that evaluated periodontal changes of MARPE appliances after maxillary expansion[51-53] have not directly measured gingival thickness and gingival level changes after maxillary expansion with

MARPE appliances. Therefore, it is not possible to directly compare the findings of our study with previous findings.

5.3 Correlation of Gingival and Osseous Changes

The correlation of changes (from T_1 to T_2) in gingival levels (GL) and gingival thickness (GTRP2) was calculated against buccal bone thickness at 3 and 6mm (BBT3, BBT6) from CEJ, and buccal bone marginal levels (BBML), using Spearman Correlations statistics. Results showed that GL changes did not correlate with any of the osseous parameters around any of the tooth groups analyzed in both appliances. This result is in contrast with the study conducted by Löst et al.,[23] where they evaluated the prevalence of gingival recessions and buccal bone dehiscences around 113 affected teeth in 27 adults with an average age of 25.6 years. They reported that a clinically measured 1mm increase in gingival recession led to a 0.98mm increase in bony dehiscence level measured surgically; indicating a strong correlation between the changes in gingival and osseous levels. However, such correlation between gingival levels and buccal bone marginal levels was not established in our study.

In our analysis, gingival thickness changes (ΔGTRP2) correlated with buccal bone thickness changes at 3mm from CEJ (ΔBBT3) only for the second premolars in the Dresden appliance group (Rho=of 0.918, p-value < 0.036). Since this correlation was limited to the second premolars in the Dresden group and the remaining teeth as well as the Moon expander group did not show any statistical significance, results should be interpreted with caution and may not be clinically significant.

The lack of correlation between most gingival and osseous parameter changes could be attributed to the time of acquisition of data used in this study. The CBCT and Intraoral records were taken before and shortly after the maxillary expansion was completed. However, gingival and osseous changes could take months to years to develop, and it is unknown if these changes occur at the same rate. Therefore, while analysis of the results and data in this study can help identify short-term soft and hard tissue changes, long-term effects cannot be determined using this data. Therefore, studies with long-term follow-up periods may prove to be beneficial to assess if changes in osseous and gingival parameters truly correlate.

5.4 Assessment of Risk Factors by Photo-analysis

Lack of keratinized tissue width, thin keratinized tissue, presence of inflammation, and presence of existing gingival recession have all been previously identified to be local risk factors associated with the development of further gingival recession.[13, 20, 64, 65] The Intraoral photos taken from patients before (T_1) and after (T_2) maxillary expansion (using MARPE appliances) were examined. Maxillary first premolars, second premolars, and first molars were scored for each of the above factors and changes in each risk factor were scored as no-change (0), worsened (+1), and improved (-1). Results showed that keratinized tissue thickness and width hardly changed after maxillary expansion with either appliance, whereas the incidence of worsened inflammation and gingival recession increased after expansion with either appliance.

One would expect that in the Moon expander group, presence of orthodontic bands around the maxillary first molars could potentially hinder the patients' oral hygiene and result in greater gingival inflammation around the first molars. However, the Chi-square/Fisher Exact analysis of the distribution of changes in these factors for each tooth type indicated that there is no difference between the two appliances in any of the factors mentioned above. Therefore, results showed that the type of appliance does not significantly affect inflammation or gingival recession. However, it is important to emphasize that such visualizations are based on a short-term analysis of the data and future long-term studies are recommended.

5.5 Limitations

5.5.1 General Considerations

This analysis was a retrospective study which relied upon data previously acquired as part of an ongoing investigation on MARPE appliances and their effect on adults. As such, the methodology used to evaluate the periodontal changes induced by MARPE had to be adapted so that it would be compatible with the available records.

The subjects had CBCT, intraoral photos, and intraoral scan records taken before and shortly (within a month) after maxillary expansion was completed. As previously discussed, some of the periodontal changes that occur after the maxillary expansion may not be immediate and may take longer before they can be measured. In the study by Lim et al.,[51] the negative changes in the buccal bone thickness and buccal marginal levels seen immediately after maxillary expansion was partially reversed by the one-year follow-up timepoint. This can be explained by the rebound effect following maxillary expansion. Our study did not include this follow-up period and any effect of rebound could not be determined.

Lastly, periodontal records of patients including several traditional periodontal parameters such as probing depths (PD), clinical attachment levels (CAL), and bleeding score (BS) were not available for analysis. In a clinical setting, these parameters are the primary tools to assess patients' periodontal status over a period and could have provided additional data in assessing the periodontal effects of expansion using MARPE appliances.

5.5.2 Limitation of CBCT Resolution

Generally, smaller voxel sizes allow for better evaluation of specific landmarks and for measurements. Conversely, the larger the voxel size is, the lower the spatial resolution of the scan, and the less the precision of measurements will be.[66-68] The current study utilized CBCT imaging obtained with a voxel size of 0.3mm. This resolution is the same as the resolution used in the study by Digregorio et al.,[55] whose methodology was adapted here. A 0.3 mm voxel size is the same or lower than previous studies that investigated the periodontal effects of maxillary expansion including changes in the buccal bone thickness via CBCT analysis.[51-53, 69] Moreover, Timock et al.[70] compared buccal bone thickness and height via CBCT analysis to direct measurements on 12 cadaver heads. The correlation coefficients between CBCT and direct measurements were found to be 0.98 for buccal both thickness and 0.86 for the buccal bone height. These correlation values indicate a strong agreement between the CBCT and direct measurements and provide evidence in support of using CBCTs with such voxel size for these types of linear measurements. Similarly, Hekmatian et al.[71] measured mandibular thickness on 16 dry mandibles with permanent dentition using 0.3mm (FOV of 15 cm, 85 kVp, 10 mAs, 0.30 mm voxel, 14 s scan time) and 0.15mm (15 cm, 85 kVp, 42 mAs, 0.15 mm voxel, 14 s scan) voxel size CBCT protocols. The authors found no statistically significant difference between the two protocols.[71]

Nevertheless, some studies have provided conflicting results on accuracy limit of linear measurements based on the voxel size of the CBCT protocol. Specifically, the spatial resolution of the CBCT machine with the 0.3mm voxel size setting used in this study has been previously determined to be 0.6-0.8mm.[67] Therefore, some authors have recommended that caution should be taken in the interpretation of results when measuring small distances less than this spatial resolution.[66-68] One way to circumvent this limit would be to decrease the voxel size in order to increase the imaging resolution. However, the acquisition of a higher resolution of CBCT imaging will inevitably lead to a higher radiation dose delivered to the patient.[68] Thus, authors such as Molen[68] have suggested that CBCT imaging with higher resolution and smaller fields of view be used in the measurement of small changes such as buccal bone thickness measurements. This would allow for more precise measurements while reducing the effects of scatter artifacts and allowing for lower radiation exposure to patients.

5.5.3 Limitations of Photo-analysis

In this study, different gingival risk factors were evaluated using photo-analysis of the intraoral photos at T_1 and T_2 timepoints. Photo-analyses were completed by two trained examiners and scoring was performed as a consensus decision between the two examiners. The photo-analysis scoring method utilized in this study was adapted from Kobewka,[58] whose methodology was modified from that of Le Roch et al..[72] In the study conducted by Le Roch et al.,[72] the author evaluated scoring systems such as Cairo et al.'s Root esthetic system,[59] Kerner's before and after scoring system (Bass),[73] and Fürhauser's Pink Esthetic score system.[61] Le Roch et al.[72] reported that agreement between different examiners on the factors measured was good for gingival recession ($\kappa>0.60$) and gingival inflammation based on colour ($\kappa>0.6$). However, this agreement was poor for determining the location of the mucogingival junction and assessing soft tissue volume.

In the present study, changes in gingival recession and inflammation were noted for both treatment groups and different tooth-types, while keratinized tissue thickness and width did not appear to undergo significant changes. Since the location of MJG and assessment of soft tissue volume both had a low agreement, as determined by Le Roch et al.,[72] and these factors are directly related to the determination of keratinized tissue width and thickness, it may be possible that photo-analysis may not have high sensitivity to changes in Keratinized tissue thickness and width.

Conversely, results of present study for changes in these factors between the appliances should be taken with caution.

Chapter 6 - Conclusions, Clinical Implications, and Future Recommendations

6.1 Conclusions

1. Expansion with MARPE appliances resulted in 0.31mm reduction of buccal bone thickness, 6 mm from CEJ around mesiobuccal root of maxillary first molars. This change was not seen around the maxillary first and second premolars. The type of appliance used also had no statistically significant effect.

2. No statistically significant changes were found for buccal bone thickness 3mm from CEJ (BBT3), buccal bone marginal levels (BBML), gingival levels (GL), and gingival thickness (GTRP2) around any of the tooth types analyzed from T_1 to T_2. Appliance type also had no significant effect.

3. Within the timeframe of this study, gingival thickness changes (GTRP2) correlated with changes in buccal bone thickness 3mm from CEJ (BBT3) only around maxillary second premolars in the Dresden appliance group. No correlation was found between the changes in other gingival and the osseous parameters for any other tooth type and appliance type. However, this finding may not have clinical significance given the short timeframe of the study.

4. The results of photo-analysis indicated that the incidence development of gingival inflammation and gingival recession increased for both appliance types. However, the distribution of the changes for these risk factors associated with future gingival recession was not significantly different between the two appliances. Furthermore, keratinized tissue width (KTW) and keratinized tissue thickness (KTT) had minimal changes after maxillary expansion with either appliance group.

6.2 Clinical Implications

This retrospective study evaluated the osseous and soft tissue changes after maxillary expansion in adults, using miniscrew assisted rapid palatal expansion (MARPE). The result of the study indicated a 0.31mm reduction in buccal bone thickness around the mesio-buccal root of maxillary first molars. The type of appliance did not have a statistically significant effect on these changes. This finding could be clinically significant if the buccal bone thickness around the maxillary first molars is thin prior to maxillary expansion. In these scenarios, patients could have bony dehiscence around maxillary first molars, and this would predispose these sites to gingival recession in the long term.[17, 24] Therefore, it may be beneficial for the clinicians to evaluate the buccal bone thickness around the teeth in proximity to where the MARPE appliances exert forces (maxillary first molars, for instance), prior to maxillary expansion using MARPE appliances. Additionally, if there is significantly thin or narrow zone of keratinized tissues in such areas, referral to a periodontist may be appropriate. In such cases, pre-emptive soft tissue grafting to increase width and thickness of keratinized tissues to reduce risk of uncontrolled recession may be indicated and should be considered.

In addition, since the type of MARPE appliance did not have a statistically significant effect on the osseous and gingival changes, and the risk factors for further recession, it gives the clinicians flexibility in terms of what type of MARPE appliance to use. Scenarios where the clinicians could benefit from using Dresden appliance (compared to Moon appliance) are when patients have large restorations on maxillary first molars, have multiple missing teeth, or have significant amount of posterior crowding. On the other hand, if the root proximity between posterior teeth prevents appropriate placement of the miniscrews, Moon appliance might be a preferred option.

6.3 Future research recommendations

- Future studies with larger sample sizes as well as long-term follow-up periods of at least one year could be conducted to evaluate osseous and gingival parameter changes after maxillary expansion with MARPE appliances.
- As recommended by Molen,[68] the use of higher-resolution CBCT imaging with a smaller voxel size and smaller field of view limited to the teeth being examined may prove to be beneficial in the measurement of parameters such as buccal bone height and thickness, while limiting radiation exposure to the patient.
- Periodontal charting including chairside measurements of pocket depth (PD), gingival levels (GL), bleeding on probing (BOP), plaque score (PS), and clinical attachment level (CAL) is recommended to be performed in addition to CBCT and intraoral records. Keratinized tissue width and keratinized tissue thickness can also be measured clinically, and these findings could prove to be more accurate than retrospective methods of gingival assessment, such as those employed in photo-analysis in our study.

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Appendix

Table A3.1 Hypothesis statements

#	**Hypothesis**
1	H_0: There are no differences in buccal bone thickness measured at root point 3 (BBT3) and root point 6 (BBT6) as well as buccal bone marginal level (BBML) from T_1 to T_2 in maxillary first molars, first premolars or second premolars, regardless of the appliance type. H_a: At least one of BBT3,BBT6, BBML is different from T_1 to T_2 in maxillary first molars, first premolars or second premolars, regardless of the appliance type
2	H_0: There are no differences in buccal bone thickness measured at root point 3 (BBT3) and root point 6 (BBT6) as well as buccal bone marginal level (BBML) from T_1 to T_2 between Dresden and Moon appliances in maxillary first molars, first premolars or second premolars. H_a: at least one of BBT3,BBT6, BBML in appliances is different than the other in maxillary first molars, first premolars or second premolars
3	H_0: There are no differences in buccal gingival thickness measured at root point 2 (GTRP2) well as Buccal gingival level (GL) from T_1 to T_2 in maxillary first molars, first premolars or second premolars, regardless of the appliance type. H_a: at least of GTRP2, GL is different from T_1 to T_2 , regardless of the appliance type
4	H_0: There are no differences in buccal gingival thickness measured at root point 2 (GTRP2) well as buccal gingival level (GL) from T_1 to T_2 between Dresden and Moon appliances in maxillary first molars, first premolars or second premolars. H_a: at least one of GTRP2 or GL from T_1 to T_2 in one of the appliances is different than the other in maxillary first molars, first premolars or second premolars
5	H_0: There are no correlations between any of the osseous parameters (BBML, BBT6, BBT3) and gingival parameters (GL, GTRP2) from T_1 to T_2 in maxillary first premolars, second premolars or first molars. H_1: There is correlation between at least one of BBML, BBT6, BBT3 and GL or GTRP2 from T_1 to T_2 in maxillary first premolars, second premolars or first molars.
6	H_0: There is no difference in the distribution of crosstabulation in Δ KTT, Δ KTW, Δ Inf, ΔGR calculated from T_2-T_1 in maxillary first premolars, second premolars or first molars between the two appliances. H_0: There is a difference in crosstabulation in at least one of Δ KTT, Δ KTW, Δ Inf, ΔGR calculated from T_2-T_1 in maxillary first premolars, second premolars or first molars between the two appliances.

Table A3.2 Data Analysis Methodology

Data were collected on Maxillary first premolars, second premolars, and first molars and analyzed in the following steps to answer research question in Section 1.5.1

A) To answer research question # 1, the following parameters were measured from CBCT records (at T_1 and T_2): BBT3, BBT6, and BBML for Dresden and Moon appliance groups. Changes in these parameters were analyzed with time (PrePost) as the within-subject factor.

B) To answer research question # 2: data obtained in step A were further analyzed using "ApplianceType" as a between-subject factor interacting with time (PrePost *ApplianceType).

C) To answer research question # 3: CBCT and Intraoral scan records were combined for measurement of GTRP2 and GL (at T_1 and T2). Changes were analyzed with time (PrePost) as the within-subject factor.

D) To answer research question # 4: Data obtained in Step C were further analyzed with "ApplianceType" as the between-subject factor interacting with time (PrePost *ApplianceType).

E) To answer research question # 5: Correlation statistics were performed on the data obtained in steps B and D and correlations between changes in Osseous and Gingival parameters were reported.

F) To answer research question # 6: Photoanalysis was performed on intraoral photographs of the analyzed teeth to visually assess for specific gingival parameters/risk factor changes at T_1 and T_2. Distribution of changes obtained for both groups were analyzed.

Table A4.1 Descriptive statistics for osseous and gingival parameters

			Pre-expansion (T_1)		Post-expansion (T_2)		$\Delta(T_1-T_2)$		N
Tooth-type (maxillary)	Parameter	Appliance	Mean	Std Deviation	Mean	Std Deviation	Mean	Std Deviation	
First Premolars	BBT3	Dresden	1.20	0.55	1.04	0.44	-0.16	0.40	8
		Moon	1.28	0.37	0.85	0.61	-0.43	0.53	15
		Overall	1.25	0.43	0.91	0.56	-0.34	0.49	23
	BBT6	Dresden	1.31	0.53	1.14	0.58	-0.17	0.41	11
		Moon	1.33	0.58	1.24	0.56	-0.09	0.55	17
		Overall	1.32	0.55	1.20	0.56	-0.12	0.49	28
	BBML	Dresden	4.20	3.26	4.99	3.88	0.79	2.09	16
		Moon	4.04	3.55	5.33	4.40	1.29	3.44	22
		Overall	4.10	3.39	5.19	4.14	1.08	2.92	38
	GL	Dresden	-0.50	1.13	-0.08	0.94	0.41	0.57	16
		Moon	-0.49	0.78	-0.36	0.91	0.13	0.45	21
		Overall	-0.49	0.93	-0.24	0.92	0.25	0.52	37
	GTRP2	Dresden	1.22	0.42	1.41	0.49	0.18	0.36	16
		Moon	1.39	0.33	1.30	0.38	-0.09	0.23	22
		Overall	1.32	0.38	1.35	0.43	0.03	0.32	38
Second Premolars	BBT3	Dresden	1.56	0.87	1.35	0.88	-0.21	0.47	11
		Moon	1.64	0.53	1.36	0.64	-0.28	0.64	17
		Overall	1.61	0.67	1.35	0.73	-0.25	0.57	28
	BBT6	Dresden	1.95	0.58	1.92	0.54	-0.03	0.41	16
		Moon	2.02	0.41	1.84	0.48	-0.18	0.38	21
		Overall	1.99	0.48	1.87	0.50	-0.12	0.40	37
	BBML	Dresden	2.58	1.25	2.59	1.08	0.01	0.68	16
		Moon	2.47	1.24	2.73	1.27	0.26	0.73	22
		Overall	2.51	1.23	2.67	1.18	0.16	0.71	38
	GL	Dresden	-0.37	1.65	-0.77	1.18	0.09	0.29	16
		Moon	-0.46	1.40	-0.59	1.33	-0.11	0.28	20

		Overall	-0.42	1.49	-0.67	1.25	-0.02	0.30	36
	GTRP2	Dresden	1.45	0.46	1.54	0.55	-0.40	1.56	15
		Moon	1.46	0.38	1.38	0.51	-0.13	0.32	18
		Overall	1.46	0.41	1.45	0.52	-0.25	1.06	33
First molars	BBT3	Dresden	1.13	1.05	0.87	0.87	-0.25	0.88	6
		Moon	1.27	0.48	0.48	0.64	-0.79	0.91	10
		Overall	1.22	0.71	0.63	0.73	-0.59	0.91	16
	BBT6	Dresden	1.46	0.48	1.44	0.62	-0.02	0.30	14
		Moon	1.51	0.52	0.92	0.62	-0.63	0.58	18
		Overall	1.47	0.54	1.12	0.69	-0.35	0.56	31
	BBML	Dresden	4.59	2.65	4.72	2.62	0.13	0.31	17
		Moon	3.85	2.12	5.69	3.16	1.84	2.94	21
		Overall	4.18	2.37	5.26	2.93	1.07	2.34	38
	GL	Dresden	-0.30	0.87	-0.23	0.96	0.07	0.28	17
		Moon	0.73	1.15	0.86	1.12	0.13	0.44	12
		Overall	0.13	1.11	0.22	1.15	0.09	0.35	29
	GTRP2	Dresden	1.44	0.38	1.39	0.20	-0.06	0.24	17
		Moon	1.33	0.63	1.18	0.78	-0.15	0.33	19
		Overall	1.38	0.52	1.28	0.58	-0.11	0.29	36

Table A4.2 Assumption testing for one-way repeated measure mixed ANOVA

To ensure ANOVA tests provide valid statistical results, several assumptions must be met. These assumptions include sphericity assumption, normal distribution of data, independent sampling, Equality of Error Variance of samples, and absence of significant outliers.

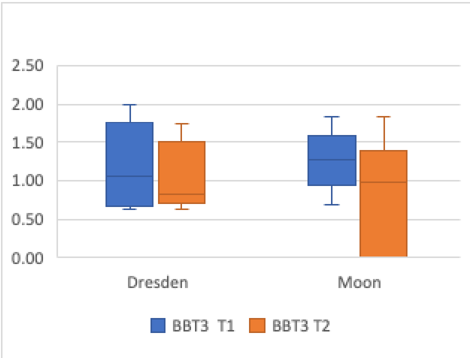
Since both the within-subject and between-subject factors only had 2 levels each, the data were assumed to be spherical. Data were also independently sampled, and the data collected from one patient was not influenced by data collection from another patient. Therefore, the independent sampling assumption was also met.

Levene's test of equal variance (shown in Table A4.3, Appendix) yielded p-values of >0.05 for all parameters tested, indicating that the data had equal error variance. Therefore, this assumption was also met.

The presence of outliers was checked using examination of box plots of data as indicated in Figures A4.1, A4.2 and A4.3 and studentization of data. Few outliers were identified using the box plots, however upon studentization of data, no significant outlier with a value +/- >3.00 was identified. Therefore, absence of significant outlier assumption was considered met.

Shapiro Wilk test was conducted to evaluate the normality of the data for BBT3, BBT6, BBML, GL, and GTRP2 for maxillary first premolars, second premolars, and first molars at T_1 and T_2. Data are shown cased in Table A4.4 (Appendix). Most of the data demonstrated to be normal except for the following: for maxillary first premolars, the BBML values were not normally distributed for both appliances at T_1 and T_2. The GTRP2 was also not normally distributed at T_1 for both Dresden and Moon appliances. For the second premolars, at T_1, the BBT3 values for the Dresden group and the BBT3 values for the Overall groups were not normally distributed. Also, BBML values at T_1 for overall groups and the BBML at T_2 for the Moon expander group were not normally distributed. For maxillary first molars, BBT3 values for both groups at T_2, BBT6 values for both groups and T_2, BBML for both groups at T_1 and T_2, and the GTRP2 values for the Moon expander group at T_1 were not normally distributed.

Although some data were not normally distributed, since the ANOVA test is generally considered robust against departure from normality therefore the assumption can be considered met.



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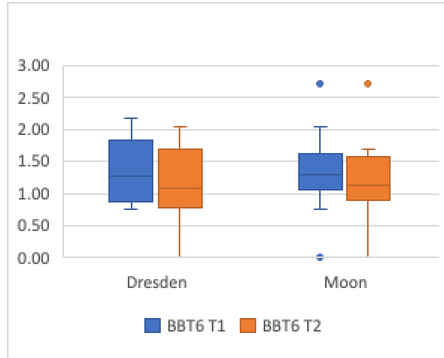

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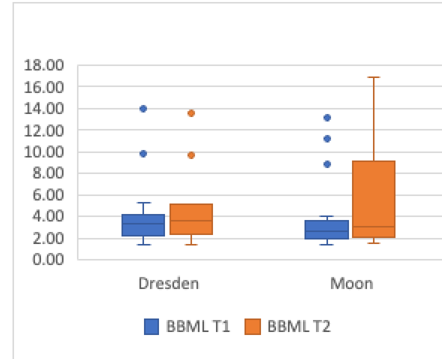

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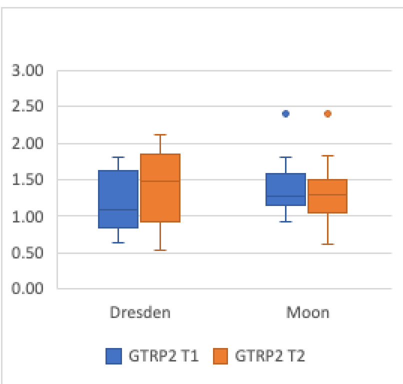

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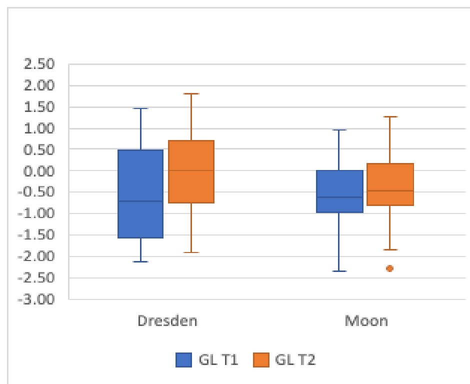
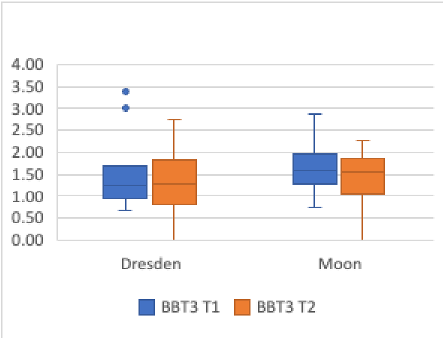


E

Figure A4.1 Box plots of osseous and gingival data in Maxillary First Premolars

T1 indicates pre-expansion data and T2 indicated Post expansion data. Data is shown for both Dresden appliance and Moon Expander group.



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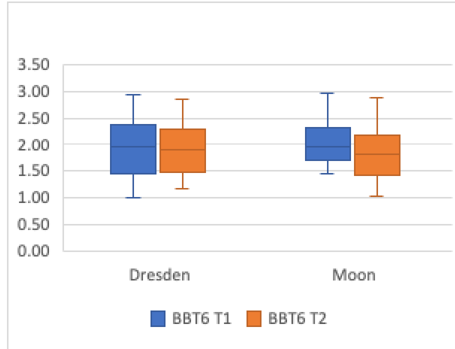

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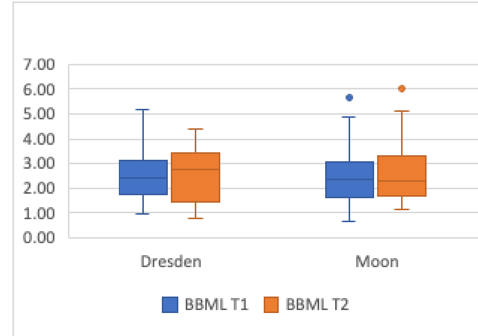

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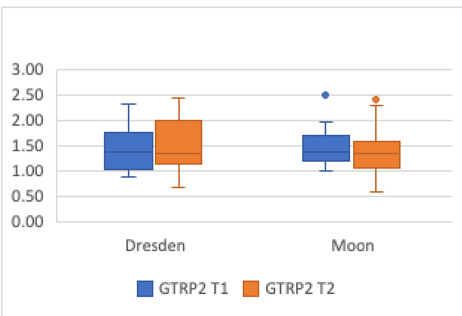

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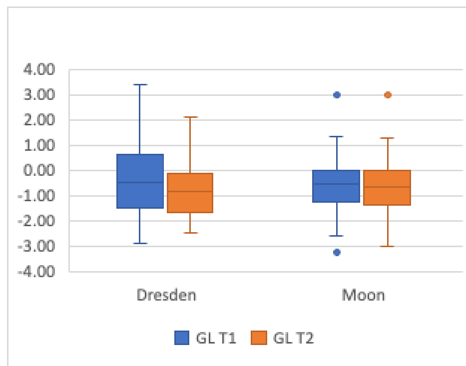
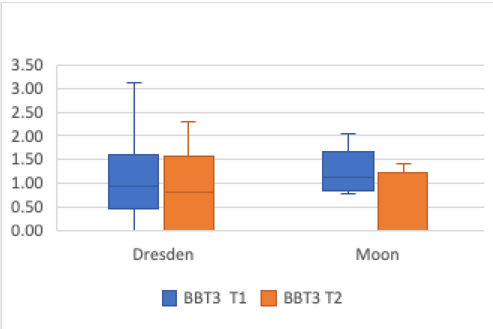


E

Figure A4.2 Box plots of osseous and gingival data in Maxillary Second Premolars

T1 indicates pre-expansion data and T2 indicates Post expansion data. Data is shown for both Dresden Appliance and Moon Expander groups.



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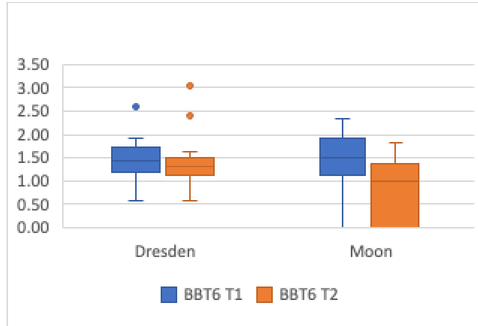

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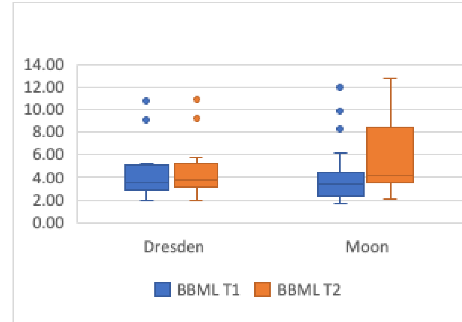
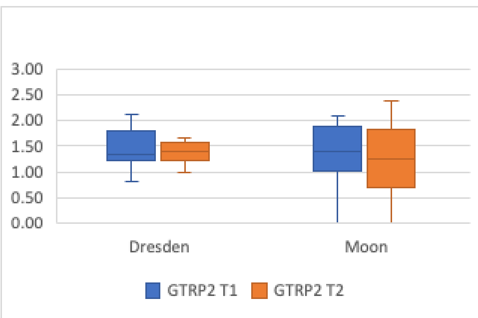
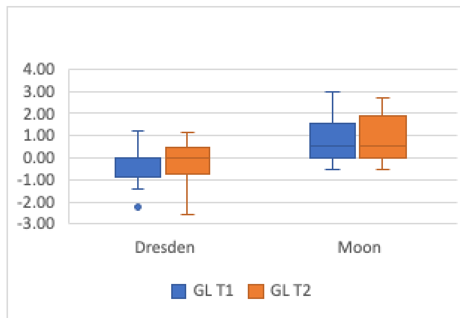


C



D



E

Figure A4.3 Box plots of osseous and gingival data in Maxillary First Molars

T1 indicates pre-expansion data and T2 indicates Post expansion data. Data is shown for both Dresden Appliance and Moon Expander groups.

Table A4.3 Levene's Test of Equality Error Variances of Osseous and Gingival parameters at T1 and T2 time points

Tooth-type (Maxillary)			Levene Statistic	df1	df2	Sig.
First Premolars	BBT3 T1	Based on Mean	3.432	1	21	0.078
	BBT3 T2	Based on Mean	1.198	1	21	0.286
	BBT6 T1	Based on Mean	0.021	1	26	0.885
	BBT6 T2	Based on Mean	0.134	1	26	0.717
	BBML T1	Based on Mean	0.414	1	36	0.524
	BBML T2	Based on Mean	0.92	1	36	0.344
	GL T1	Based on Mean	3.83	1	35	0.058
	GL T2	Based on Mean	0.026	1	35	0.873
	GTRP2 T1	Based on Mean	4.693	1	36	0.37
	GTRP2 T2	Based on Mean	2.636	1	36	0.113
Second Premolars	BBT3 T1	Based on Mean	2.046	1	26	0.165
	BBT3 T2	Based on Mean	1.256	1	26	0.273
	BBT6 T1	Based on Mean	2.87	1	35	0.099
	BBT6 T2	Based on Mean	0.497	1	35	0.485
	BBML T1	Based on Mean	0.034	1	36	0.856
	BBML T2	Based on Mean	0.119	1	36	0.732
	GL T1	Based on Mean	0.693	1	34	0.411
	GL T2	Based on Mean	0.077	1	34	0.783
	GTRP2 T1	Based on Mean	1.986	1	31	0.169
	GTRP2 T2	Based on Mean	0.696	1	31	0.411
First Molars	BBT3 T1	Based on Mean	1.099	1	14	0.312
	BBT3 T2	Based on Mean	0.204	1	14	0.658
	BBT6 T1	Based on Mean	1.047	1	30	0.403
	BBT6 T2	Based on Mean	1.055	1	30	0.483
	BBML T1	Based on Mean	0.001	1	36	0.402
	BBML T2	Based on Mean	2.477	1	36	0.320
	GL T1	Based on Mean	0.676	1	27	0.418
	GL T2	Based on Mean	0.684	1	27	0.416
	GTRP2 T1	Based on Mean	2.66	1	34	0.112
	GTRP2 T2	Based on Mean	18.294	1	34	0.1234

Table A4.4 Tests of normality of osseous and gingival parameters

Tooth-type (Maxillary)		**Appliance**	**Shapiro-Wilk**		
			Statistic	df	Sig.
First Premolars	BBT3 T1	Dresden	0.871	8	0.156
		Moon	0.946	15	0.47
		Overall	0.935	23	0.143
	BBT3 T2	Dresden	0.833	8	0.064
		Moon	0.899	15	0.092
		Overall	0.939	23	0.172
	BBT6 T1	Dresden	0.882	11	0.11
		Moon	0.954	17	0.53
		Overall	0.969	28	0.545
	BBT6 T2	Dresden	0.967	11	0.856
		Moon	0.916	17	0.126
		Overall	0.95	28	0.203
	BBML T1	Dresden	0.71	16	**<.001**
		Moon	0.668	22	**<.001**
		Overall	0.695	38	**<.001**
	BBML T2	Dresden	0.744	16	**<.001**
		Moon	0.786	22	**<.001**
		Overall	0.778	38	**<.001**
	GTRP2 T1	Dresden	0.879	16	**0.037**
		Moon	0.906	22	**0.04**
		Overall	0.968	38	0.349
	GTRP2 T2	Dresden	0.949	16	0.474
		Moon	0.945	22	0.249
		Overall	0.986	38	0.898
	GL T1	Dresden	0.952	16	0.521
		Moon	0.95	21	0.343
		Overall	0.972	37	0.472
	GL T2	Dresden	0.988	16	0.998
		Moon	0.972	21	0.782
		Overall	0.981	37	0.765
Second Premolars	BBT3 T1	Dresden	0.826	11	**0.021**
		Moon	0.962	17	0.672
		Overall	0.908	28	**0.018**
	BBT3 T2	Dresden	0.953	11	0.68
		Moon	0.911	17	0.105
		Overall	0.941	28	0.119
	BBT6 T1	Dresden	0.978	16	0.943

		Moon	0.936	21	0.177
		Overall	0.981	37	0.773
	BBT6 T2	Dresden	0.925	16	0.2
		Moon	0.981	21	0.94
		Overall	0.96	37	0.206
	BBML T1	Dresden	0.927	16	0.22
		Moon	0.933	22	0.145
		Overall	0.938	38	**0.036**
	BBML T2	Dresden	0.949	16	0.478
		Moon	0.88	22	0.012
		Overall	0.946	38	0.063
	GTRP2 T1	Dresden	0.931	15	0.278
		Moon	0.905	18	0.07
		Overall	0.945	33	0.098
	GTRP2 T2	Dresden	0.951	15	0.548
		Moon	0.965	19	0.671
		Overall	0.963	34	0.302
	GL T1	Dresden	0.957	16	0.606
		Moon	0.971	20	0.772
		Overall	0.966	36	0.337
	GL T2	Dresden	0.937	16	0.317
		Moon	0.937	20	0.207
		Overall	0.951	36	0.112
First Molars	BBT3 T1	Dresden	0.837	6	0.123
		Moon	0.87	10	0.1
		Overall	0.899	16	0.077
	BBT3 T2	Dresden	0.924	6	0.538
		Moon	0.717	10	**0.001**
		Overall	0.814	16	**0.004**
	BBT6 T1	Dresden	0.961	14	0.739
		Moon	0.953	18	0.571
		Overall	0.979	32	0.774
	BBT6 T2	Dresden	0.839	14	**0.016**
		Moon	0.893	18	0.123
		Overall	0.934	32	**0.049**
	BBML T1	Dresden	0.8	17	**0.002**
		Moon	0.753	21	**0.001**
		Overall	0.78	38	**<.001**
	BBML T2	Dresden	0.805	17	**0.002**
		Moon	0.88	21	**0.016**
		Overall	0.853	38	**<.001**
	GTRP2 T1	Dresden	0.931	17	0.225
		Moon	0.899	19	**0.046**

	Overall	0.919	36	**0.012**
GTRP2 T2	Dresden	0.954	17	0.521
	Moon	0.928	19	0.16
	Overall	0.914	36	**0.008**
GL T1	Dresden	0.943	17	0.359
	Moon	0.873	12	0.071
	Overall	0.94	29	0.099
GL T2	Dresden	0.946	17	0.392
	Moon	0.913	12	0.233
	Overall	0.964	29	0.404

Table A4.5 Test of within subject-effects

Tooth-type (Maxillary)	Parameter		Type III Sum of Squares	df	Mean Square	F	Sig.	Adjusted Sig.
First Premolars	**BBT3**	PrePost	0.91	1	0.91	7.69	0.011	0.33
		PrePost * ApplianceType	0.19	1	0.19	1.63	0.216	1.00
		Error(PrePost)	2.49	21	0.12			
	BBT6	PrePost	0.23	1	0.23	1.79	0.193	1.00
		PrePost * ApplianceType	0.02	1	0.02	0.16	0.689	1.00
		Error(PrePost)	3.28	26	0.13			
	BBML	PrePost	20.19	1	20.19	4.63	0.038	1.00
		PrePost * ApplianceType	1.16	1	1.16	0.27	0.610	1.00
		Error(PrePost)	156.86	36	4.36			
	GL	PrePost	1.35	1	1.35	10.46	0.003	0.09
		PrePost * ApplianceType	0.35	1	0.35	2.74	0.107	1.00
		Error(PrePost)	4.51	35	0.13			
	GTRP2	PrePost	0.04	1	0.04	1.04	0.316	1.00
		PrePost * ApplianceType	0.35	1	0.35	8.27	0.007	0.21
		Error(PrePost)	1.51	36	0.04			
Second Premolars	**BBT3**	PrePost	0.81	1	0.81	4.84	0.037	1.00
		PrePost * ApplianceType	0.02	1	0.02	0.10	0.757	1.00
		Error(PrePost)	4.37	26	0.17			
	BBT6	PrePost	0.20	1	0.20	2.55	0.119	1.00
		PrePost * ApplianceType	0.11	1	0.11	1.34	0.255	1.00
		Error(PrePost)	2.73	35	0.08			
	BBML	PrePost	0.35	1	0.35	1.40	0.245	1.00

		PrePost * ApplianceType	0.30	1	0.30	1.20	0.281	1.00
		Error(PrePost)	8.96	36	0.25			
	GL	PrePost	1.23	1	1.23	2.16	0.151	1.00
		PrePost * ApplianceType	0.32	1	0.32	0.57	0.456	1.00
		Error(PrePost)	19.29	34	0.57			
	GTRP2	PrePost	0.00	1	0.00	0.04	0.843	1.00
		PrePost * ApplianceType	0.16	1	0.16	3.85	0.059	1.00
		Error(PrePost)	1.26	31	0.04			
First Molars	**BBT3**	PrePost	2.05	1	2.05	5.09	0.041	1.00
		PrePost * ApplianceType	0.54	1	0.54	1.34	0.266	1.00
		Error(PrePost)	5.66	14	0.40			
	BBT6	PrePost	1.53	1	1.53	13.14	<0.001	**<0.03**
		PrePost * ApplianceType	1.29	1	1.29	11.10	0.002	0.06
		Error(PrePost)	3.49	30	0.12			
	BBML	PrePost	18.07	1	18.07	7.44	0.010	0.30
		PrePost * ApplianceType	13.66	1	13.66	5.62	0.023	0.69
		Error(PrePost)	87.47	36	2.43			
	GL	PrePost	0.14	1	0.14	2.30	0.141	1.00
		PrePost * ApplianceType	0.01	1	0.01	0.21	0.649	1.00
		Error(PrePost)	1.66	27	0.06			
	GTRP2	PrePost	0.19	1	0.19	4.43	0.043	1.00
		PrePost * ApplianceType	0.04	1	0.04	0.85	0.363	1.00
		Error(PrePost)	1.46	34	0.04			

Table A4.6 Pairwise Comparisons for BBT6 in Maxillary first molars from T1 to T2

(I) PrePost Lower Bound	(J) PrePost Upper Bound	Mean Difference (mm)	Std. Error	Sig.
1	2	.31*	0.09	**0.001**
2	1	-.31*	0.09	**0.001**

Table A4.7 Tests of normality of changes in osseous and gingival parameters in patients who had expansion with Dresden and Moon Appliances

Tooth-type (maxillary)		Appliance	Shapiro-Wilk		
			Statistic	df	Sig.
First Premolars	ΔBBT3	Dresden	0.91	8	0.356
		Moon	0.923	15	0.217
	ΔBBT6	Dresden	0.888	11	0.132
		Moon	0.933	17	0.24
	ΔBBML	Dresden	0.488	16	**<.001**
		Moon	0.481	22	**<.001**
	ΔGTRP2	Dresden	0.941	16	0.36
		Moon	0.949	22	0.297
	ΔGL	Dresden	0.81	16	**0.004**
		Moon	0.893	22	**0.022**
Second Premolars	ΔBBT3	Dresden	0.958	11	0.746
		Moon	0.877	17	**0.029**
	ΔBBT6	Dresden	0.907	16	0.106
		Moon	0.94	21	0.215
	ΔBBML	Dresden	0.897	16	0.072
		Moon	0.818	22	**<.001**
	ΔGTRP2	Dresden	0.79	15	**0.003**
		Moon	0.751	19	**<.001**
	ΔGL	Dresden	0.566	16	**<.001**
		Moon	0.791	22	**<.001**
First Molars	ΔBBT3	Dresden	0.853	6	0.168
		Moon	0.94	10	0.549
	ΔBBT6	Dresden	0.922	14	0.235
		Moon	**0.881**	**17**	**0.033**
	ΔBBML	Dresden	0.905	17	0.083
		Moon	**0.705**	**21**	**<.001**
	ΔGTRP2	Dresden	0.941	17	0.333
		Moon	**0.896**	**16**	**0.07**
	ΔGL	**Dresden**	**0.899**	**17**	**0.065**
		Moon	**0.709**	**21**	**<.001**

Table A4.8 Spearman's Rho correlation analysis of gingival and osseous changes

Tooth-type	Appliance	Correlating parameters	Spearman's rho	Significanc e (2-tailed)	Adjusted Significance (p-value)*
First Premolars	Dresden	ΔGL - ΔBBML	-0.025	0.927	1
		ΔGL - ΔBBT6	0.118	0.729	1
		ΔGL- ΔBBT3	-0.31	0.456	1
		ΔGTRP2 - ΔBBML	0.418	0.107	1
		ΔGTRP2 - ΔBBT6	0.209	0.537	1
		ΔGTRP2 - ΔBBT3	-0.333	0.42	1
	Moon	ΔGL - ΔBBML	-0.014	0.95	1
		ΔGL- ΔBBT6	0.53	0.029	1
		ΔGL- ΔBBT3	0.111	0.693	1
		ΔGTRP2 - ΔBBML	-0.294	0.184	1
		ΔGTRP2 - ΔBBT6	-0.362	0.154	1
		ΔGTRP2 - ΔBBT3	0.129	0.648	1
Second Premolars	Dresden	ΔGL - ΔBBML	0.178	0.509	1
		ΔGL - ΔBBT6	-0.343	0.194	1
		ΔGL- ΔBBT3	0.064	0.853	1
		ΔGTRP2 - ΔBBML	-0.475	0.074	1
		ΔGTRP2 - ΔBBT6	0.011	0.97	1
		ΔGTRP2 - ΔBBT3	0.918	<.001	**<0.036**
	Moon	ΔGL- ΔBBML	0.58	0.005	0.18
		ΔGL- ΔBBT6	0.218	0.342	1
		ΔGL- ΔBBT3	-0.304	0.235	1
		ΔGTRP2 - ΔBBML	-0.168	0.491	1
		ΔGTRP2 - ΔBBT6	0.044	0.858	1
		ΔGTRP2 - ΔBBT3	-0.144	0.594	1
First Molars	Dresden	ΔGL - ΔBBML	0.31	0.227	1
		ΔGL - ΔBBT6	-0.214	0.462	1
		ΔGL- ΔBBT3	-0.086	0.872	1
		ΔGTRP2 - ΔBBML	-0.047	0.859	1
		ΔGTRP2 - ΔBBT6	0.134	0.648	1
		ΔGTRP2 - ΔBBT3	-0.314	0.544	1
	Moon	ΔGL - ΔBBML	0.425	0.055	1
		ΔGL - ΔBBT6	0.089	0.734	1
		ΔGL- ΔBBT3	0.406	0.244	1
		ΔGTRP2 - ΔBBML	-0.282	0.289	1
		ΔGTRP2 - ΔBBT6	0.159	0.603	1
		ΔGTRP2 - ΔBBT3	0.143	0.736	1

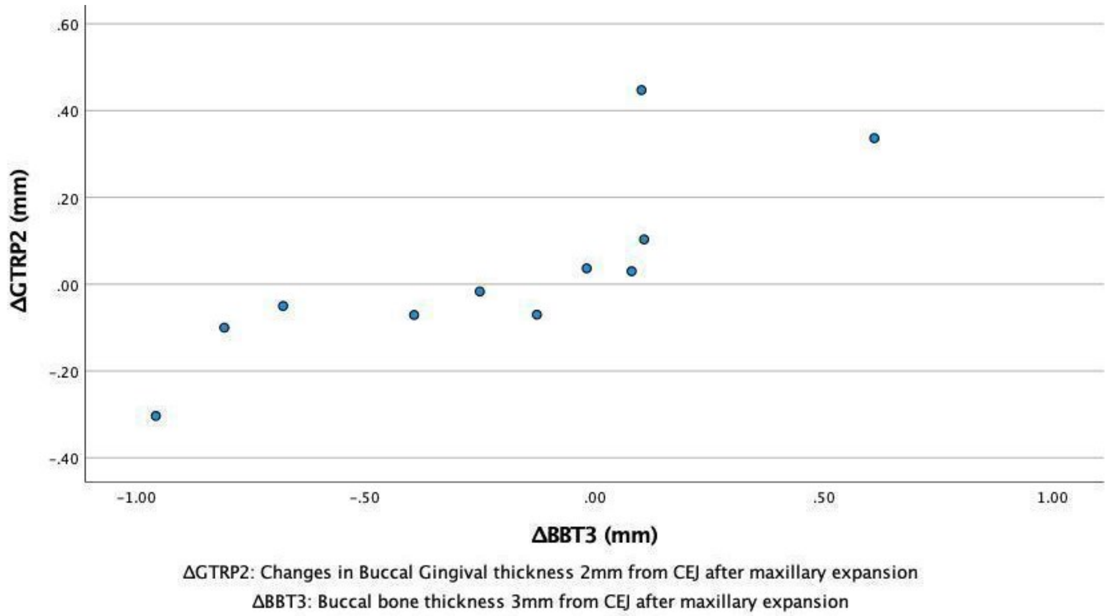


Figure A4.4 Scatter Plot of ΔGTRP2 vs ΔBBT3 of second premolars in the Dresden appliance group

Table A4.9 Crosstabulation of frequency of change in photo-analysis variables among Dresden appliance and Moon expander groups

			Frequency		
Tooth-type			**Dresden**	**Moon**	**Total**
Max First Premolars	**ΔKTT**	-1 (Improved)	0	0	0
		0 (No change)	16	22	38
		1 (Worsened)	0	0	0
		Total	16	22	38
	ΔKTW	-1 (Improved)	1	0	1
		0 (No change)	15	21	36
		1 (Worsened)	0	1	1
		Total	16	22	38
	ΔInf	-1 (Improved)	1	3	4
		0 (No change)	8	11	19
		1 (Worsened)	7	8	15
		Total	16	22	38
	ΔGR	-1 (Improved)	1	0	1
		0 (No change)	8	7	15
		1 (Worsened)	7	15	22
		Total	16	22	38

Max Second Premolars	**ΔKTT**	-1 (Improved)	0	0	0
		0 (No change)	17	22	39
		1 (Worsened)	0	0	0
		Total	17	22	39
		-1 (Improved)	0	0	0
	ΔKTW	0 (No change)	17	22	39
		1 (Worsened)	0	0	0
		Total	17	22	39
	ΔInf	-1 (Improved)	0	1	1
		0 (No change)	11	13	24
		1 (Worsened)	6	8	14
		Total	17	22	39
	ΔGR	-1 (Improved)	0	0	0
		0 (No change)	8	7	15
		1 (Worsened)	7	15	22
		Total	16	22	38
Max First molars		-1 (Improved)	0	0	0
	ΔKTT	0 (No change)	16	19	35
		1 (Worsened)	0	0	0
		Total	16	19	35
	ΔKTW	-1 (Improved)	0	0	0
		0 (No change)	16	19	35
		1 (Worsened)	0	0	0
		Total	16	22	38
	ΔInf	-1 (Improved)	0	3	3
		0 (No change)	6	6	12
		1 (Worsened)	10	10	20
		Total	16	19	35
	ΔGR	-1 (Improved)	0	1	1
		0 (No change)	13	9	22
		1 (Worsened)	3	9	12
		Total	16	19	35

Table A4.10 Fisher's Exact test/Pearson Chi-Square analysis of distribution of changes in recession risk factors between Dresden and Moon appliances

Tooth-type	Parameter	N		Value	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Adjusted sig
Max First premolars	ΔKTT	38	Fisher-Freeman-Halton Exact Test	1.971		0.671	1
	ΔInf	38	Fisher-Freeman-Halton Exact Test	0.619		0.898	1
	ΔGR	38	Fisher-Freeman-Halton Exact Test	3.004		0.231	1
Max Second Premolars	ΔInf	39	Fisher-Freeman-Halton Exact Test	0.812		1	1
	ΔGR	39	Pearson Chi-Square	5.110[a]	0.024		0.168
Maxillary First Molars	ΔInf	35	Fisher-Freeman-Halton Exact Test	2.426		0.345	1
	ΔGR	35	Fisher-Freeman-Halton Exact Test	4.318		0.078	0.546