Original Article

Alveolar Bone Macroscopic Changes as a Response to Light Controlled-tipping Maxillary Dental Arch Expansion in Young Adults: A Cone-beam Computed Tomography Study

Chanchai Pattanaviriyapisan[1], Chairat Chareomratrote[2], Udom Thongudomporn[2]

[1]Dental department, Kanchanadit hospital, Suratthani

[2]Department of Preventive Dentistry, Faculty of Dentistry, Prince of Songkla University, Songkhla

Abstract

The objectives of this study were to examine the amount of expansion, the changes of molar inclination, crown and root position of maxillary first molars, as well as changes of alveolar bone thickness, alveolar bone height and buccal bone position by using cone-beam computed tomography (CBCT) after light controlled-tipping expansion in young adult subjects. Factors related to changes in alveolar bone thickness (ABT) were also investigated. Maxillary dental expansion was performed in twenty-four patients (age 15.3-26.5-year-old) with orthodontic fixed appliances and a straight rectangular titanium molybdenum alloy (TMA®) wire which produced 126 ± 27 g of expansion force. Dento-alveolar changes were evaluated using CBCT images acquired before (T_0) and 3 months after expansion (T_1). Mann-Whitney U-tests, Wilcoxon matched pairs signed rank tests, Kruskal-Wallis test with the Dunn-Bonferroni tests were used to compare the changes. Spearman's rank correlation analysis was performed to identify factors associated with the changes of ABT. The significance level was set at .05. Significant buccal controlled-tipping of the first molars occurred leading to a significant increase of intermolar width (IMW) ($P<0.01$). ABT at bucco-crestal site of mesio-buccal root (ABT-MB-L1) significantly decreased ($P<0.05$), while ABT at palatal sites (ABT-Pa) significantly increased ($P<0.05$). Buccal bone position (BucBonePos) significantly displaced buccally ($P<0.05$). ΔIMW and the rate of expansion significantly positively related to ΔABT-MB-L1 ($P<0.05$). Initial ABT was significantly negatively correlated with ΔABT-MB-L1 and ΔABT-Pa ($P<0.05$). The study concluded that some degrees of ABT-MB-L1 reduction and ABT-Pa gain were observed when applying force lower than 130 g for controlled-tipping maxillary dental arch expansion. These changes were related to ΔIMW, rate of expansion, and initial ABT. Buccal displacement of outer surface of bucco-crestal bone was observed.

Keywords: Cone-beam computed tomography, Slow maxillary expansion, Alveolar bone change, Light force

Received Date: Jan 22, 2019 **Revised Date:** Feb 13, 2019 **Accepted Date:** Mar 21, 2019

Doi: 10.14456/jdat.2019.36

Correspondence to:

Udom Thongudomporn. Department of Preventive Dentistry, Faculty of Dentistry, Prince of Songkla University, Hat Yai, Songkhla 90112 Thailand, Tel: 074-429875 E-mail: udom2t@gmail.com

Introduction

Determining how alveolar bone responses to orthodontic tooth movement have interested researchers over the years because the quality and quantity of the bone surrounding the teeth in final position justify the success and prognosis of treatment. The concept that orthodontic force induces alveolar bone resorption on the pressure side and bone apposition on the tension side has been well accepted.[1] However, at macroscopic level, it has been demonstrated that bone remodeling: tooth movement ratio is not a 1:1 basis in maxillary incisor retraction studies.[2,3] Studies on the changes of alveolar bone thickness after rapid maxillary expansion (RME) provide similar results.[4] Generally, as the posterior teeth are expanded, reduced buccal alveolar thickness, especially at the crestal level, and increased palatal alveolar thickness are observed.[5,6]

High force magnitude produced from RME appliances may provoke the occurrence of reduced buccal bone thickness during maxillary arch expansion.[6,7] An alternative protocol so called slow maxillary expansion (SME) providing lower force systems has been proposed.[8] Using light force to move teeth may minimize the occurrence of undermining resorption, and may reduce lag phase during tooth movement.[9] Light force could be advantageous not only to the adjacent alveolar bone, but also to the neighboring cortical bone of the loaded area resulting in displacement of both tooth and alveolar bone.[10] However, results with regards to alveolar bone response following SME have been controversial.[11] A study applying an Alveolar Development Appliance (ADA) which produces 300 g of continuous expansion force on the palatal alveolar bone of maxillary posterior teeth found evidence of young bone formation on the buccal aspect of the teeth.[11] In contrast, Brunetto *et al.,* (2013)[12] compared the effects of RME and SME and demonstrated that vertical and horizontal bone losses were found in both groups with greater bone loss shown in SME group. Most SME appliances such as quad-helix, or NiTi expander produce a significant degree of buccal crown tipping of the posterior teeth,[4,13] which may generate excessive stress at the buccal alveolar crest leading to the loss of bucco-crestal alveolar thickness.

To minimize expansion force and to decrease posterior buccal crown tipping, maxillary dental expansion method proposed by Gill *et al.,*[14] was modified by using a straight rectangular titanium molybdenum alloy (TMA®) wire with the largest size of wire that sufficiently fits into the bracket slots to produce anti-buccal tipping torque. Due to the relatively low load deflection and stiffness characteristics of TMA® wire, light force is generated although a large range of activation is performed.[15] According to our pilot laboratory test on a series of 10 untreated maxillary models, when a straight 0.016”×0.022” TMA® wire was bent into an arch form with an intermolar width of 43-47 mm, the wire produced 126 ± 27 g of total expansion force.

The objectives of this prospective cone-beam computed tomography (CBCT) study were to examine the amount of expansion, the changes of molar inclination, crown and root position of maxillary first molars, as well as changes of alveolar bone thickness, alveolar bone height and buccal bone position after maxillary dental arch expansion with orthodontic fixed appliance in combination with light force by using straight rectangular TMA® wire in a group of young adult subjects. In addition, factors that might relate to changes in alveolar bone thickness during expansion were investigated.

Materials and Methods

Subjects and study protocol

This prospective cohort study was performed at the Faculty of Dentistry, Prince of Songkla University under the approval of the faculty ethical committee (Ethic approval No. EC 5803-13-P-HR). Informed consent was obtained from subjects who agreed to participate in this study. For under 20-year-old subjects, the consent forms were signed by the parents. The sample size was calculated by G*Power (Version 3.1)[16] using parameters taken from a quad helix appliance study on changes in alveolar bone around the maxillary first molars[17] (mean difference of alveolar bone thickness = 1.6 mm, difference of standard deviation = 1.3 mm, significance level = 0.05, power = 0.90). A sample size of 18 subjects was required. To increase the power of the study, 24 subjects (10 males, 14 females) aged 15.3-26.5-year-old with mean age ± SD of 19.2 ± 2.8-year-old were involved in this study.

The inclusion criteria were: (1) no more than 4 mm bilateral maxillary dental expansion required, (2) hypo- or normo-divergent facial pattern (15°≤SN-GoMe≤35°) that would allow an increase in lower facial height by creating clockwise rotation of the mandible, (3) no unilateral or posterior crossbite, (4) presence of all permanent teeth from right to left maxillary second molars, (5) no metal crown on posterior teeth, (6) healthy periodontal condition without gingival recession or signs of traumatic occlusion, (7) no craniofacial disorders, (8) no underlying disease and no signs and symptoms of temporomandibular joint disorders. Exclusion criteria were the occurrence of periodontal gingival pockets ≥4 mm or progressive gingival recession during treatment, missed appointments, and early arch width corrected during the aligning and leveling stage.

Subjects were treated using 0.018”×0.025” slot pre-adjusted edgewise brackets from left to right second premolars (Roth system, Master Series™; American Orthodontics®, Sheboygan, WI, USA) and buccal tubes (Non-convertible, LP™; American Orthodontics®, Sheboygan, WI, USA) on left and right maxillary first molars. Instruction on oral care was given after bonding. Leveling and alignment were accomplished by progressing the archwires from 0.012”, 0.014”, 0.016”×0.016”, and 0.016”x0.022” Ni-Ti. CBCT imaging was taken before starting maxillary expansion (T_0). CBCT (3D Accuitomo 170®, J Morita Mfg. Corp., Kyoto, Japan) was performed at 90 kV and 5 mA with a 17.5-second exposure time, 0.25 mm voxel resolution and 100 × 100 mm field of view. Arch expansion was accomplished using a straight length of 0.016”×0.022” beta-titanium alloy wire (TMA®, Ormco™, Orange, CA, USA). The TMA® wire was tied to all brackets using ligature wires. Every 3-4 weeks the wire was removed, straightened, and re-engaged in the brackets. Periodontal status was determined by measuring the depths of gingival pockets and recording presence or absence of gingival recession on the maxillary posterior teeth.

When maxillary posterior arch width was expanded to the determined amount, the maxillary arch was maintained with a 0.016”×0.022” passive stainless steel wire for 3 months to allow bone remodeling (T_1).[18] At T_1, CBCT imaging was performed.

CBCT analysis

Changes of crown and root position, alveolar bone thickness and height between T_0 and T_1 were determined from the CBCT scans. All CBCT scans were viewed on OneVolumeViewer® software (OneVolume Viewer®, version 11.0; J Morita Mfg. Corp., Kyoto, Japan). The CBCT images were oriented base on three planes which were respectively constructed: 1) sagittal plane connecting the mid-cranial base and anterior nasal spine (ANS); 2) axial plane from the ANS to posterior nasal spine (PNS); and 3) coronal plane perpendicular to the axial plane passing through the points to be measured.[12] Five sections of coronal plane (C-plane1 to C-plane5) were established for the measurement of different parameters (Table 1).

C-plane1 was used to measure intermolar width (IMW). C-plane2 was used to measure first molar inclination (6Incl), crown position (CrownPos), root position (RootPos), alveolar bone height (ABH), total alveolar bone thickness (TotalABT) and buccal bone position (BucBonePos). For the measurement of alveolar bone thickness (ABT), C-plane3 – C-plane5 were used to measure ABT of mesio-buccal (MB), disto-buccal (DB), and palatal (Pa) root, respectively (Fig. 1-3). Definitions of nine dental and seventeen alveolar bone variables are presented in Table 1.

Table 1 *Definitions of abbreviations, reference lines and measurements used in this study*

Operation terms	Description
Reference lines	
Mid-S-line	Mid sagittal line: a vertical line connecting the mid-cranial base and anterior nasal spine
H-line	Horizontal line: a perpendicular line to Mid-S-line passing the highest point of the palatal vault
Coronal plane sections (C-plane)	Five coronal plane sections for each measurement
C-plane1	C-plane passing through the central pit of right and left molars
C-plane2	C-plane passing through the bifurcation between Pa and DB of right and left molars
C-plane3	C-plane passing through the widest side of MB root of each molars
C-plane4	C-plane passing through the widest side of DB root of each molars
C-plane5	C-plane passing through the widest side of Pa root of each molars
Dental measurements	
IMW	Intermolar width: distance between central pit of right and left molars on the C-plane1
6Incl	Molar inclination: an angle formed by a line connecting between the deepest pit and the mid-furcation intersecting with the line perpendicular to Mid-S-line on the C-plane2
Crown position (CrownPos)	
H- CrownPos	Horizontal crown position: perpendicular distance from Mid-S-line to the deepest pit of the maxillary first molar on the C-plane2
V- CrownPos -B	Vertical buccal crown position: distance from the buccal CEJ perpendicular to H-line on the C-plane2
V- CrownPos -Pa	Vertical palatal crown position: distance from the palatal CEJ perpendicular to H-line on the C-plane2
Root position (RootPos)	Perpendicular distance from Mid-S-line to the outer most surface of the first molar root on the C-plane2
RootPos -L1	Root position at 3.0 mm apical to the CEJ
RootPos -L2	Root position at 6.0 mm apical to the CEJ
RootPos -L3	Root position at 9.0 mm apical to the CEJ
RootPos -L4	Root position at apex of the root
Alveolar bone measurements	
Alveolar bone thickness (ABT)	Perpendicular distance to Mid-S-line, ranging from the surface of MB, DB, and Pa root to the outer most surface of the bone measured on C-plane3, C-plane4 and C-plane5, respectively.
ABT-MB-L1, ABT-MB-L2, ABT-MB-L3	ABT of MB root at 3.0, 6.0, and 9.0 mm apical to the CEJ respectively
ABT-DB-L1, ABT-DB-L2, ABT-DB-L3	ABT of DB root at 3.0, 6.0, and 9.0 mm apical to the CEJ respectively
ABT-Pa-L1, ABT-Pa-L2, ABT-Pa-L3	ABT of Pa root at 3.0, 6.0, and 9.0 mm apical to the CEJ respectively
Alveolar bone height (ABH)	Perpendicular distance to H-line ranging from CEJ to the same side of alveolar crest level measured on C-plane2
ABH-B	ABH ranging from buccal CEJ to buccal alveolar bone crest
ABH-Pa	ABH ranging from palatal CEJ to palatal alveolar bone crest
Total alveolar bone thickness (TotalABT)	Perpendicular distance to Mid-S-line ranging between the outer most surface of the buccal and palatal bone in each level measured on C-plane2
TotalABT-L1, TotalABT-L2, TotalABT-L3	TotalABT at 3.0, 6.0, and 9.0 mm apical to the CEJ espectively
Buccal bone position (BucBonePos)	Perpendicular distance to Mid-S-line ranging from Mid-S-line to the outer most surface of buccal alveolar bone in each level measured on C-plane2
BucBonePos-L1, BucBonePos-L2, BucBonePos -L3	BucBonePos at 3.0, 6.0, and 9.0 mm apical to the CEJ respectively

A horizontal line (H-line) perpendicular to sagittal plane passing the highest point of the palatal vault was constructed. Perpendicular distances of all bony points to H-line from T_0 CBCT images were registered and transferred to the T_1 CBCT images to determine ∆ABT, ∆TotalABT, and ∆BucBonePos.

All CBCT measurements were performed by an investigator who was blinded from subjects' identity and the sequence of materials being measured. All data from 10 randomly selected subjects were measured twice at 4 weeks apart to assess reliability by using paired *t*-tests and to assess measurement error by using Dalberg's formula,[19] respectively. Paired *t*-tests revealed no significant differences between the two sets of replicate measurements (P=0.35) and Dahlberg's error was 0.4 mm and 0.4° for linear and angular variables, confirming the measurements were reliable.

Statistical analysis

Shapiro-Wilk tests showed non-normally distribution of some parameters. Consequently, Mann-Whitney *U*-tests, Wilcoxon matched pairs signed rank tests, and Kruskal-Wallis test with the Dunn-Bonferroni tests were used to compare the changes between sexes and changes within group, as appropriate. Spearman's rank correlation analysis was performed to identify factors associated with ∆ABT. All calculations were performed using statistical software (SPSS, version 23; IBM, New York, NY, USA) with a significance level of 0.05.

Results

There was no significant difference in pretreatment arch width, molar inclination and amount of expansion between sexes of all subjects; therefore, the data for male and female subjects were pooled. Moreover, since changes of bilateral variables were not statistically significant, mean values between sides were considered.

Table 2 Comparisons of Means ± Standard Deviations (SD) of intermolar width, crown and root position between T_0 and T_1

Variables	T_0 Mean ± SD	T_1 Mean ± SD	T_1-T_0			*P*-value‡
			Mean ± SD	Min-Max	*P*-value†	
IMW (mm)	45.8 ± 2.2	47.8 ± 2.8	1.9 ± 1.1	0.9-3.9	0.00**	
6Incl (degree)	89.6 ± 2.4	91.6 ± 2.3	2.1 ± 0.9	-0.1-3.9	0.00**	
V-CrownPos-B (mm)	14.7 ± 2.9	14.6 ± 3.1	-0.1 ± 0.7	-1.1-0.5	0.17	
V-CrownPos-Pa (mm)	14.6 ± 2.9	14.7 ± 2.9	0.1 ± 0.5	-1.2-0.5	0.58	
H-CrownPos (mm)	23.0 ± 1.1	23.8 ± 1.4	0.8 ± 0.6[a]	0.2-1.7	0.00**	
RootPos-L1 (mm)	27.5 ± 1.2	28.0 ± 1.3	0.5 ± 0.2[b]	0.1-1.0	0.00**	
RootPos-L2 (mm)	28.0 ± 1.4	28.1 ± 1.3	0.1 ± 0.2[c]	-0.3-0.4	0.06	0.02*
RootPos-L3 (mm)	28.4 ± 1.3	28.5 ± 1.2	0.1 ± 0.4[c]	-0.4-0.5	0.26	
RootPos-L4 (mm)	28.4 ± 1.2	28.4 ± 1.2	0.0 ± 0.1[c]	-0.2-0.2	0.90	

IMW, intermolar width; 6Incl, molar inclination; CrownPos, crown position; RootPos, root position; V, vertical; H, horizontal; B, buccal; Pa, palatal; L1, 3.0 mm from cemento-enamel junction (CEJ); L2, 6.0 mm from CEJ; L3, 9.0 mm from CEJ; L4, root apex

† P-value of Wilcoxon matched-pairs signed-ranks test comparing difference between T_0 and T_1 of each variable.

‡ P-value of Kruskal–Wallis test comparing differences of changes of crown and root position within each tooth. Different letters represent statistically significant differences.

** Statistically significant at P<0.05, ** P<0.01*

Table 2 shows crown and root changes between T_0 and T_1. IMW significantly increased by 1.9 ± 1.1 mm (*P*<0.01) (range: 0.9-3.9 mm). First molar crowns significantly moved buccally (ΔH-CrownPos = 0.8±0.6 mm; *P*<0.01) but revealed non-significant extrusion (ΔV-CrownPos-B = -0.1 ± 0.7 mm, ΔV-CrownPos-Pa = 0.1±0.5 mm; *P*>0.05). Roots showed no significant change in bucco-palatal dimension in all levels (*P*>0.05), except for RootPos-L1 (ΔRootPos-L1 = 0.5 ± 0.2 mm; *P*<0.01). The movement could be considered as controlled-tipping.[20]

Significant decrease of ABT-MB-L1 was observed (ΔABT-MB-L1 = -0.20 ± 0.18 mm; *P*<0.05), but ABT of all levels of palatal root significantly increased (*P*<0.05). BucBonePos-L1 significantly increased (ΔBucBonePos-L1 = 0.07 ± 0.15 mm; *P*<0.05) indicating that buccal surface of the alveolar bone at L1 level displaced buccally. No significant changes of TotalABT, ABH-B, and ABH-Pa were observed (*P*>0.05) (Table 3).

Table 3 *Comparison of Means ± Standard Deviations (SD) of alveolar bone measurement between T_0 and T_1*

Variables	Before expansion (T_0)	3 months of maintenance (T_1)	T_1-T_0	*P*-value†
	Mean ± SD	Mean ± SD		
ABT-MB-L1 (mm)	1.92 ± 0.50	1.70 ± 0.60	-0.20 ± 0.18	0.01*
ABT-MB-L2 (mm)	2.44 ± 0.96	2.38 ± 1.00	-0.06 ± 0.25	0.27
ABT-MB-L3 (mm)	2.62 ± 0.92	2.56 ± 0.97	0.05 ± 0.35	0.44
ABT-DB-L1 (mm)	2.44 ± 0.50	2.38 ± 0.43	-0.06 ± 0.26	0.26
ABT-DB-L2 (mm)	3.45 ± 0.87	3.40 ± 0.95	-0.06 ± 0.19	0.17
ABT-DB-L3 (mm)	3.48 ± 0.88	3.45 ± 0.89	-0.02 ± 0.10	0.24
ABT-Pa-L1 (mm)	1.57 ± 0.34	1.75 ± 0.20	0.18 ± 0.24	0.01*
ABT-Pa-L2 (mm)	2.11 ± 1.02	2.31 ± 0.94	0.20 ± 0.19	0.01*
ABT-Pa-L3 (mm)	2.70 ± 1.87	2.92 ± 1.88	0.20 ± 0.26	0.01*
ABH-B (mm)	2.01 ± 0.28	1.98 ± 0.37	-0.03 ± 0.26	0.54
ABH-Pa (mm)	2.01 ± 0.29	2.06 ± 0.32	0.05 ± 0.13	0.06
TotalABT-L1 (mm)	15.13 ± 1.12	15.12 ± 1.07	-0.01 ± 0.15	0.89
TotalABT-L2 (mm)	16.87 ± 1.79	16.86 ± 1.78	-0.01 ± 0.08	0.60
TotalABT-L3 (mm)	18.51 ± 2.30	18.57 ± 2.37	0.06 ± 0.23	0.21
BucBonePos-L1 (mm)	28.26 ± 1.30	28.32 ± 1.32	0.07 ± 0.15	0.04*
BucBonePos-L2 (mm)	29.00 ± 1.10	29.02 ± 1.09	0.03 ± 0.07	0.12
BucBonePos-L3 (mm)	30.09 ± 1.11	30.12 ± 1.10	0.02 ± 0.12	0.31

ABT, alveolar bone thickness; ABH, alveolar bone height; TotalABT, total alveolar bone thickness; BucBonePos, buccal bone position; MB, mesio-buccal root; DB, disto-buccal root; Pa, palatal root; L1, 3.0 mm from cemento-enamel junction (CEJ); L2, 6.0 mm from CEJ; L3, 9.0 mm from CEJ.

† P-value of Wilcoxon matched-pairs signed-ranks test

** Statistically significant at P<0.05.*

Regarding correlation analysis, ∆ABT-MB-L1 showed significant correlations with ∆IMW (r=0.77; *P*<0.01), rate of expansion (r=0.51; *P*<0.05), and initial ABT-MB-L1 (r=-0.42; *P*<0.05). For ∆ABT-Pa-L1 and ∆ABT-Pa-L2, significant correlations with initial ABT-Pa-L1 and ABT-Pa-L2 were found respectively. (r=-0.85 and -0.52; *P*<0.01, respectively) (Table 4).

Table 4 *Correlations between the changes of alveolar bone thickness and position and some factors.*

Variables	R			
	∆IMW	Rate of expansion	∆6Incl	Initial ABT
∆ABT-MB-L1	0.77**	0.51*	0.18	-0.42*
∆ABT-Pa-L1	0.32	0.01	0.14	-0.85**
∆ABT-Pa-L2	0.02	-0.05	0.01	-0.52**
∆ABT-Pa-L3	0.04	0.20	-0.23	0.20
∆BucBonePos-L1	-0.24	-0.27	-0.10	0.06

R, correlation coefficients, Spearman's rank correlation analysis

ABT, alveolar bone thickness; BucBonePos, buccal bone position; MB, mesio-buccal root; Pa, palatal root; L1, 3.0 mm from cemento-enamel junction (CEJ); L2, 6.0 mm from CEJ; L3, 9.0 mm from CEJ. ∆IMW, amount of expansion; ∆6Incl, molar inclination change.

** Statistically significant at P<0.05, **P<0.01.*

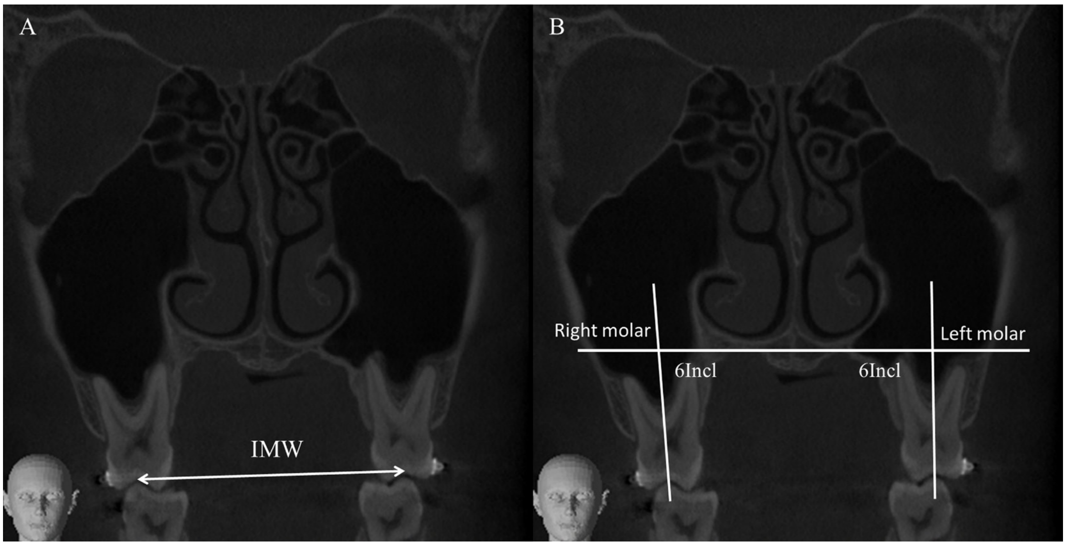

Figure 1 *(A) Measurement of intermolar width (IMW) at C-plane1. (B) Measurement of maxillary first molar inclination (6Incl) at C-plane2. (Details described in Table 1)*

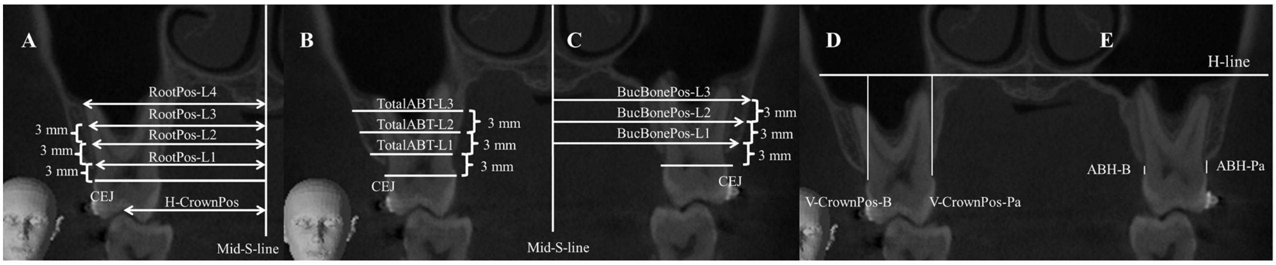

Figure 2 *(A) Measurement of crown and root positions, (B) measurement of total alveolar bone thickness (TotalABT), (C) measurement of buccal bone position (BucBonePos), (D) measurement of vertical crown position and (E) measurement of alveolar bone height at C-plane2. CEJ, cemento-enamel junction; H-CrownPos, horizontal crown position; RootPos-L1, root position at crestal level; RootPos-L2, root position at mid root level; RootPos-L3, root position at apical level; RootPos-L4, root position at apex of the root; L1, 3.0 mm apical to CEJ; L2, 6.0 mm apical to CEJ; L3, 9.0 mm apical to CEJ; H-line, Horizontal refer ence line; V-CrownPos-B, vertical buccal crown position; V-CrownPos-Pa, vertical palatal crown position; ABH-B, buccal alveolar bone height; ABH-Pa, palatal alveolar bone height (Details described in Table 1)*

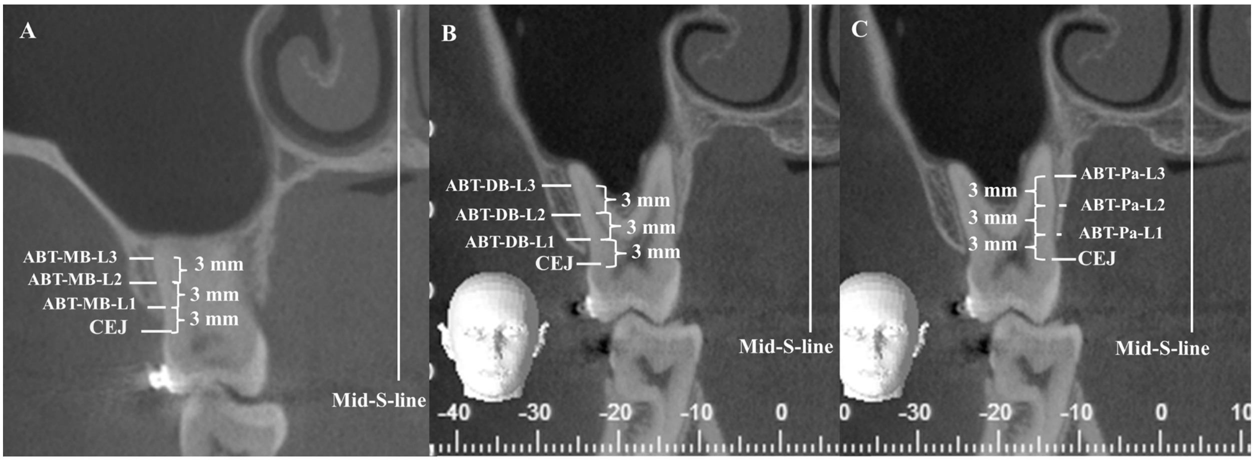

Figure 3 *Measurement of buccal and palatal alveolar bone thickness (ABT). (A) Measurement of buccal ABT of mesio-buccal root. (ABT-MB) at C-plane3. (B) Measurement of buccal ABT of disto-buccal root. (ABT-DB) at C-plane4. C) Measurement of palatal ABT of palatal root. (ABT-Pa) at C-plane5. L1, 3.0 mm apical to CEJ; L2, 6.0 mm apical to CEJ; L3, 9.0 mm apical to CEJ. (Details described in Table 1)*

Discussion

With the application of approximately 126 g of maxillary expansion force produced from a straight rectangular TMA® wire, first molars were moved buccally with minimal tipping. ABT significantly decreased on the labial side but increased on the palatal side. BucBonePos displaced buccally, whereas TotalABT and ABH remained unchanged.

The expansion rate at the molar region of our study (0.8 ± 0.2 mm/month) is comparable to that produced by quad-helix.[4] However, the degree of first molar inclination change of our study (2.1 ± 0.9°) is much less than those produced by other types of slow expanders.[4,13] Probably because of minimal tipping, molar extrusion in our study was not significant. This may subsequently lead to the ability to maintain alveolar height on both buccal and palatal sides in our study.

The significant changes of bucco-crestal and palatal bone thickness indicate a lag between bone remodeling and tooth movement, even though the force was lower than the recommended amount for dental expansion (450-900 g).[8] Our finding agrees with Kraus *et al.*, who revealed reduction of buccal bone thickness following expansion with light force in a group of young adult dogs,[21] Nevertheless, buccal drift of the alveolar process was evident, since we found that BucBonePos-L1 significantly buccally displaced indicating the existence of cortical bone remodeling. In the aforementioned dog study,[21] histological investigation revealed bone apposition not only on the trailing edges (i.e. the PDL side of the tension areas), but also on the leading edges (i.e. the palatal bone adjacent to the root apex and the periosteal side of the buccal bone in the coronal level) of the buccally tipped roots. Further biomarker study may provide more insight into the response of the alveolar bone to light expansion force.

Significant correlations between the rate of expansion and ΔABT-MB-L1, and between ΔIMW and ΔABT-MB-L1 imply that the faster the rate of expansion, the greater the probability of bucco-crestal alveolar bone thickness reduction. Also, the more the arch is expanded, the thinner the bucco-crestal alveolar bone thickness becomes. We could not find a significant correlation between change of molar inclination and change of alveolar bone thickness. This may be due to the low variability of molar inclination change (Δ6Incl = 2.1 ± 0.9 degree) which restricted the correlation analysis to detect the statistical relationship. Interestingly, we found significant negative correlation between initial ABT at MB-L1 and ΔABT. This can be interpreted that the thinner the initial buccal alveolar bone, the more alveolar bone thickness reduction would occur during expansion. The result is supported by previous findings.[5,6] Initial thickness of alveolar bone may be an indicator of remodeling capability. Further studies are needed to test this presumption.

The present study has several strengths. To ensure the accuracy of bone measurement on CBCT, we used 0.25 mm voxel size which can provide good spatial resolution for adequate visualization of the buccal bone.[22] Also, we allowed 3 months of resting period to ensure complete remodeling of the alveolar bone.[18] We measured changes of tooth position, inclination, alveolar bone thickness and alveolar bone height based on stable external references. Thus, the reading of bone changes is independent from dental changes. This provides a useful information on what really occur to the bone when the tooth is moved. Previous studies used cusp tips or root apexes as references for measuring molar inclination changes.[12] Measurements using these landmarks can be affected by root resorption or occlusal attrition occurs. In this study, we used anatomical landmarks that were minimally affected by root resorption, occlusal attrition, or molar rotation, i.e., the central pit and furcation, thereby reducing the likelihood of measurement errors over time.

Some limitations are worth mentioning. The sample size is rather small. A longer period of study involving larger number of patients should be emphasized to evaluate the periodontal adaptation and stability after expansion. Assessing the effect of growth status and gender may provide useful information on the factors affecting dental and bone changes due to expansion. A prospective comparison with other types of expander is required to confirm the efficacy, benefits and cost-effectiveness of the technique employed in this study.

Based on the results observed, light controlled-tipping expansion with a straight rectangular TMA® wire could be beneficial for a patient who needs maxillary arch expansion with minimal buccal crown tipping. However, the procedure must be performed with caution since there is a lag between alveolar bone remodeling and tooth movement, causing the reduction of buccal alveolar bone thickness. This warning should be emphasized to patients who have thin buccal alveolar bone.

Conclusion

When the maxillary dental arch was expanded using a straight rectangular TMA® wire in combination with full-fixed edgewise appliances in young adult patients, the following conclusions could be drawn:

1. The first molars moved buccally with controlled tipping manner. No dental extrusion was found.
2. Reduction of bucco-crestal thickness, but increases of palatal bone were observed. Alveolar bone height was maintained. Outer surface of buccal bone at the crestal level displaced buccally.
3. Changes of alveolar bone thickness were significantly

correlated with the amount of arch expansion, rate of expansion, and initial corresponding bone thickness.

Acknowledgements

We would like to express our gratitude to Graduate School and Faculty of Dentistry, Prince of Songkla University, for supporting this research.

References

1. Melsen B. Biological reaction of alveolar bone to orthodontic tooth movement. ***Angle Orthod*** 1999;69(2):151-8.
2. Vardimon AD, Oren E, Ben-Bassat Y. Cortical bone remodeling/tooth movement ratio during maxillary incisor retraction with tip versus torque movements. ***Am J Orthod Dentofacial Orthop*** 1998;114(5):520-9.
3. Yodthong N, Charoemratrote C, Leethanakul C. Factors related to alveolar bone thickness during upper incisor retraction. ***Angle Orthod*** 2012;83(3):394-401.
4. Huynh T, Kennedy DB, Joondeph DR, Bollen AM. Treatment response and stability of slow maxillary expansion using Haas, hyrax, and quad-helix appliances: a retrospective study. ***Am J Orthod Dentofacial Orthop*** 2009;136(3):331-9.
5. Garib DG, Henriques JFC, Janson G, de Freitas MR, Fernandes AY. Periodontal effects of rapid maxillary expansion with tooth-tissue-borne and tooth-borne expanders: a computed tomography evaluation. ***Am J Orthod Dentofacial Orthop*** 2006;129(6):749-58.
6. Rungcharassaeng K, Caruso JM, Kan JY, Kim J, Taylor G. Factors affecting buccal bone changes of maxillary posterior teeth after rapid maxillary expansion. ***Am J Orthod Dentofacial Orthop*** 2007;132 (4):428.e1-8.
7. Isaacson RJ, Ingram AH. Forces produced by rapid maxillary expansion: II. Forces present during treatment. ***Angle Orthod*** 1964;34(4):261-70.
8. Hicks EP. Slow maxillary expansion: a clinical study of the skeletal versus dental response to low-magnitude force. ***Am J Orthod*** 1978;73(2):121-41.
9. Tomizuka R, Shimizu Y, Kanetaka H, Suzuki A, Urayama S, Kikuchi M, *et al.* Histological evaluation of the effects of initially light and gradually increasing force on orthodontic tooth movement. ***Angle Orthod*** 2007;77(3):410-16.
10. Yee JA, Türk T, Elekdağ-Türk S, Cheng LL, Darendeliler MA. Rate of tooth movement under heavy and light continuous orthodontic forces. ***Am J Orthod Dentofacial Orthop*** 2009;136(2):151-9.
11. Williams MO, Murphy NC. Beyond the ligament: a whole-bone periodontal view of dentofacial orthopedics and falsification of universal alveolar immutability. ***Semin Orthod*** 2008;14(4):246–59
12. Brunetto M, Andriani Jda S, Ribeiro GL, Locks A, Correa M, Correa LR. Three-dimensional assessment of buccal alveolar bone after rapid and slow maxillary expansion: a clinical trial study. ***Am J Orthod Dentofacial Orthop*** 2013;143(5):633-44.
13. Karaman A. The effects of nitanium maxillary expander appliances on dentofacial structures. ***Angle Orthod*** 2002;72(4):344-54.
14. Gill D, Naini F, McNally M, Jones A. The management of transverse maxillary deficiency. ***Dent Update*** 2004;31(9):516-23.
15. Kusy RP, Whitley JQ. Thermal and mechanical characteristics of stainless steel, titanium-molybdenum, and nickel-titanium archwires. ***Am J Orthod Dentofacial Orthop*** 2007;131(2):229-37.
16. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. ***Behav Res Methods*** 2009;41(4):1149-60.
17. Corbridge JK, Campbell PM, Taylor R, Ceen RF, Buschang PH. Transverse dentoalveolar changes after slow maxillary expansion. ***Am J Orthod Dentofacial Orthop*** 2011;140(3):317-25.
18. Sarikaya S, Haydar B, Ciger S, Ariyürek M. Changes in alveolar bone thickness due to retraction of anterior teeth. ***Am J Orthod Dentofacial Orthop*** 2002;122(1):15-26.
19. Dahlberg G. Statistical methods for medical and biological students. ***Br Med J*** 1940;2(4158): 358–359.:358-9
20. Smith RJ, Burstone CJ. Mechanics of tooth movement. ***Am J Orthod*** 1984;85(4):294-307.
21. Kraus CD, Campbell PM, Spears R, Taylor RW, Buschang PH. Bony adaptation after expansion with light-to-moderate continuous forces. ***Am J Orthod Dentofacial Orthop*** 2014;145(5):655-66.
22. Molen AD. Considerations in the use of cone-beam computed tomography for buccal bone measurements. ***Am J Orthod Dentofacial Orthop*** 2010;137(4):130-5.