Original Article

Dentoskeletal effects of a temporary skeletal anchorage device–supported rapid maxillary expansion appliance (TSADRME): *A pilot study*

Jason William Vassar[a*]; Anastasios Karydis[b*]; Terry Trojan[c]; Jack Fisher[d]

ABSTRACT

Objective: To quantitatively evaluate maxillary skeletal expansion using cone-beam computed tomography (CBCT) images and propose a novel way to quantify the dental tipping effects of temporary skeletal anchorage device–supported rapid maxillary expansion appliance (TSADRME).

Materials and Methods: Images from 25 patients receiving rapid maxillary expansion with incorporated temporary skeletal anchorage devices (TSADs) before activation (T1) and after removal (T2) were analyzed to detect dentoskeletal changes.

Results: A significant increase from T1 to T2 was found for all linear measurements except buccal maxillary width at the canines. The greatest buccal expansion was at the first molar, decreasing anteriorly. However, the greatest palatal expansion was at the first premolar. All younger subjects (8–16 years old) exhibited less dental tipping and greater expansion overall compared with the older subjects. There was great variability in dental tipping of first molars (mean = 4.31°), with some subjects demonstrating mild uprighting of these teeth.

Conclusions: The TSADRME appliance is an effective, clinically useful device that results in mild molar tipping and may positively affect expansion in the area of TSAD placement. (*Angle Orthod.* 2016;86:241–249.)

KEY WORDS: Palatal expansion; Temporary skeletal anchorage devices

INTRODUCTION

Rapid maxillary expansion (RME) is frequently used to correct transverse dental and skeletal discrepancies. RME has been researched extensively, and different types of RME devices are available to achieve both orthodontic and orthopedic movement. However, RME is ideally obtained by the use of rigid, fixed appliances to produce heavy forces directed toward the area of

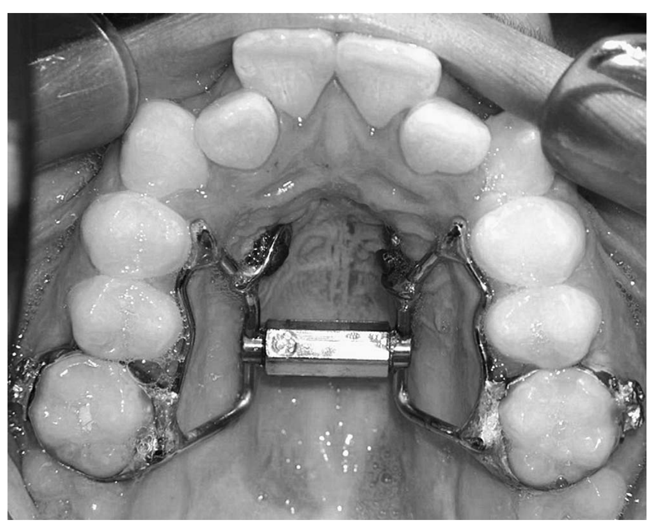

Figure 1. The temporary skeletal anchorage device–supported rapid maxillary expansion appliance (TSADRME).

[*] Authors contributed equally.

[a] Resident, Department of Orthodontics, University of Tennessee Health Science Center, College of Dentistry, Memphis, Tenn.

[b] Assistant Professor, Department of Periodontics, University of Tennessee Health Science Center, College of Dentistry, Memphis, Tenn.

[c] Associate Professor and Department Chair, Department of Orthodontics, University of Tennessee Health Science Center, College of Dentistry, Memphis, Tenn.

[d] Assistant Professor, Department of Orthodontics, University of Tennessee Health Science Center, College of Dentistry, Memphis, Tenn.

Corresponding author: Dr Anastasios Karydis, Department of Periodontics, University of Tennessee Health Science Center, College of Dentistry, 875 Union Avenue, Suite C514, Memphis, TN 38163
(e-mail: akarydis@uthsc.edu)

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Table 1. Population Age and Sex Distribution and Treatment Parameters

	M	F	Total
Age 8–16 y			
N	9	9	18
Mean age, y (Mean ± SD)	13.0 ± 2.4	13.3 ± 1.8	13.1 ± 2.1
Range age, y	8.0–15.7	10.8–15.9	8.0–15.9
Mean T1-T2, mo (Mean ± SD)	9.0 ± 2.3	7.2 ± 2.8	8.1 ± 2.5
Range T1-T2, mo	6.0–12.0	3.3–12.0	3.3–12.0
Appliance expansion, mm (Mean ± SD)	8.0 ± 1.7	8.9 ± 2.0	8.4 ± 1.8
Age >16 y			
N	3	4	7
Mean age, y (Mean ± SD)	17.3 ± 1.4	17.0 ± 1.0	17.1 ± 1.20
Range age, y	16.2–17.0	16.5–18.5	16.2–18.5
Mean T1-T2, mo (Mean ± SD)	6.9 ± 2.5	7.5 ± 3.6	7.2 ± 3.1
Range T1-T2, mo	4.7–9.7	3.1–11.2	3.1–11.2
Appliance expansion, mm (Mean ± SD)	8.7 ± 1.2	9.3 ± 3.7	9.0 ± 2.7
Location of TSADs (No.)	Ant (8), Post (4), Both (0)	Ant (6), Post (5), Both (2)	Ant (14), Post (9), Both (2)
Mean activation time, d (Mean ± SD)	8.2 ± 1.5	9 ± 2.4	8.6 ± 2.1
Rate of expansion			1 mm/d (four turns)
Appliance expansion, mm (Mean ± SD)	8.2 ± 1.5	9 ± 2.4	

[a] M indicates male; F, female; TSADs, temporary skeletal anchorage devices; Ant, anterior; and Post, posterior.

desired opening, the midpalatal suture, in order to promote maximal bony repositioning and minimal movement of the dentoalveolar structures. Orthodontic force in excess may displace maxillary posterior teeth through the cortical plate, potentially producing severe complications. Haas proposed using acrylic on the palate to concentrate the expansion force borne by bone to increase orthopedic movement and to minimize adverse dental effects. The all-wire hyrax appliance has become an alternative to the tissue-borne appliance, with the greatest important advantage being the rigidity between the jackscrew and the teeth, which promotes an immediate orthopedic response of sutural expansion.[1,2] More recent appliance designs incorporating the use of temporary skeletal anchorage devices (TSADs) attached to the teeth by a rigid framework (ie, hybrid hyrax) have been proposed to harness advantages of both the tissue-borne and tooth-borne designs to provide more orthopedic expansion and less dental tipping (Figure 1).[3–6]

Figure 2. Triangulation of the first molar furcation floor in three planes: (A) sagittal, (B) axial, and (C) coronal.

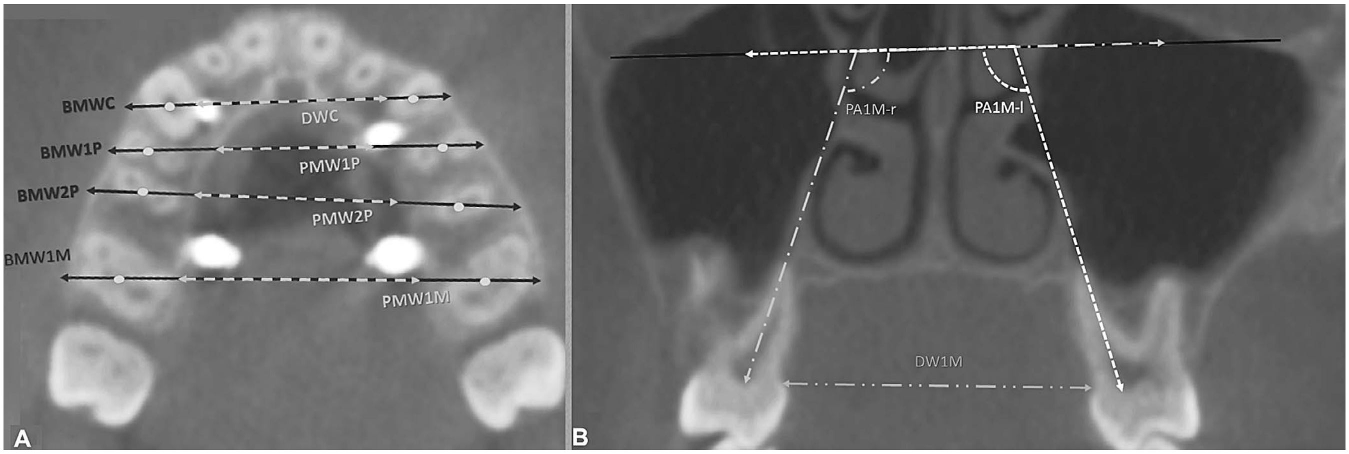


Figure 3. Measured parameters on the (A) axial and (B) coronal plane (abbreviations in Table 2).

The dentoskeletal effects, efficacy, and postexpansion stability of different RME appliance designs have been studied using cone-beam computed tomography (CBCT) and other modalities.[7–10] The evaluation of molar tipping, one of the most clinically relevant dentoskeletal effects, is not consistent in the literature.[2,10–12] The purpose of the current study was to utilize three-dimensional (3D) CBCT imaging to quantitatively evaluate maxillary skeletal expansion and to propose a novel way to quantify the dental tipping effects of a temporary skeletal anchorage device–supported rapid maxillary expansion appliance (TSADRME).

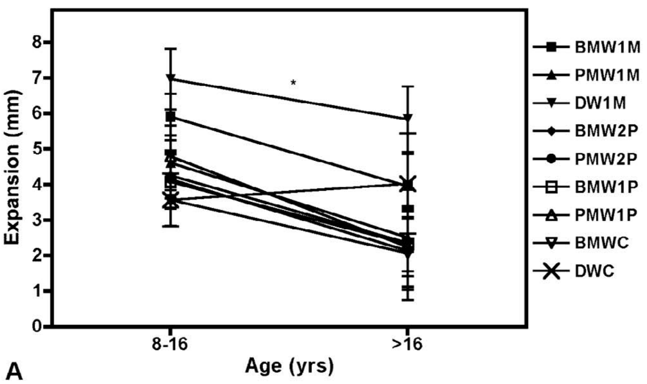
MATERIALS AND METHODS

This study was approved by the Institutional Review Board at the University of Tennessee Health Science Center (Memphis, Tenn) as a retrospective study. CBCTs from 28 patients who received RME in private practice in Memphis were available. All received appliances consisting of a hexagonal jackscrew soldered to a first molar band and rigidly attached to TSADs by acrylic. Appliances were activated by the patient/guardian until the lingual cusps of the maxillary first molars contacted the buccal cusps of the mandibular first molars and were removed following a 4-month stabilization period, following the protocol of the treating practitioner. Inclusion criteria were as follows: subjects aged 8–18 years with less than 1 year between pretreatment (T1) and posttreatment (T2) CBCT analysis to minimize growth effects. Exclusion criteria included the following: age (less than 8 years or greater than 18 years), history of craniofacial anomaly/disorder, previous maxillofacial injury/surgery, or prior orthodontic treatment.

CBCTs from 25 subjects (13 female and 12 male) were included for analysis (Table 1) and divided into two groups (ages 8–16 years and older than 16 years) to segregate for potential skeletal maturation effects. CBCTs from three subjects did not fulfill the inclusion/exclusion criteria and were removed. The mean time between T1 and T2 was 7.83 months. A previous study[12] showed no significant changes due to growth over a 6-month interval. Two tapered miniscrews (2.5 $\times$ 7.5 mm, Securus OrthoTAD; TOADS LLC; Louisville, Ky) were placed either in the anterior (C/1P region, n $=$ 14) or posterior (2P/1M region, n $=$ 9) maxilla based on the treating clinician's judgment of anatomy and root location. Four TSADs were placed in the anterior and posterior maxilla in two subjects.

Table 2. Parameters and Landmarks

Parameter	Landmarks
BMW (buccal maxillary width)	Distance between the most lateral points of buccal bone on maxilla
	BMW1M: at first molar; BMW2P: at second premolar; BMW1P: at first premolar; BMWC: at canine
PMW (palatal maxillary width)	Distance between the most medial points of palatal bone on maxilla
	PMW1M: at first molar; PMW2P: at second premolar; PMW1P: at first premolar
DWC (dental width at canine)	Distance between the most medial points of maxillary canines
DW1M (dental width at first molar)	Distance between the lingual cemento-enamel junctions of the maxillary first molars
PA1M (palatal angle at first molar)	Angle formed by the intersection of a line connecting the pulp horn and root tip of the palatal root of the maxillary first molars with a line connecting the most inferior portions bilaterally of the superior wall of the bony orbital floor
	PA1M-r, PA1M-l: at right and left first molar, respectively



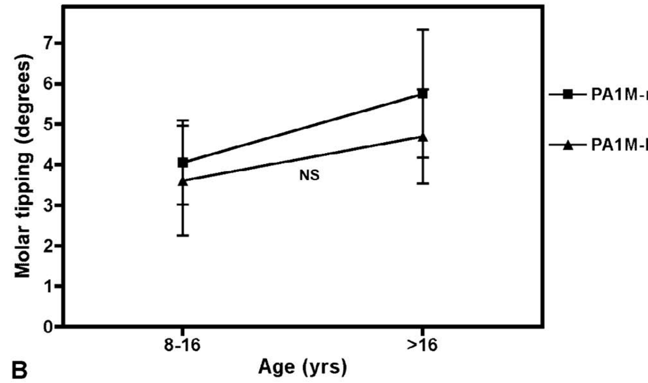


Figure 4. (A) Linear and (B) angular expansion (molar tipping) according to age group (abbreviations in Table 2) (mean ± SE) (* $P < .05$; NS indicates not significant, $P > .05$).

A Planmeca ProMax 3D scanner (Planmeca; Helsinki, Finland) was used to obtain two 20 × 17-cm field-of-view scans at 0.4-mm voxel resolution: one prior to cementation of the TSADRME (T1) and one immediately following removal (T2). The patients were scanned standing with chin rests and sighting beams for accurate and repeatable positioning. The DICOM files were imported into the OsiriX imaging software (www.osirix-viewer.com). All analyses were performed after the right and left maxillary first molars were triangulated in all three orthogonal views at 0.5-mm-thick slices (Figure 2). The sagittal plane was first established along the crista galli and the vertebral axis. The anterior and posterior nasal spines were identified on the sagittal plane to establish the orientation of the axial plane and adjusted to the furcation dome of the maxillary first molars at the level of first visualization of three distinct roots. The location of the coronal plane was determined perpendicular to the established sagittal plane and at the level of the bisector of the palatal roots of the first molars. At completion of this process, a 2D image of the axial and coronal slices was evaluated. The geometric centers of the maxillary canine (C), first premolar (1P), second premolar (2P), and first molar (1M) were determined visually and connected to establish the linear measurements in the axial plane, as shown in Figure 3A. The dental width at the maxillary first molar (DW1M) and the palatal angle for the right and left maxillary first molar (PA1M-r and PA1M-l) were assessed in the coronal plane (Figure 3B). The palatal angle was formed by the intersection of a line connecting the pulp horn and the root tip of the first molar palatal root with a line connecting the most inferior portion bilaterally of the superior wall of the bony orbital floors. Table 2 includes a description of all parameters and landmarks used.

Statistical Analysis

Examiners were standardized, and interexaminer and intraexaminer reliability was determined with the intraclass correlation coefficient (ICC) and ranged from 0.939 to 0.99 for all variables. Means, standard deviations (SDs), and standard errors (SEs) were assessed for all variables, and analysis for statistically significant changes ($P < .05$) was performed. Pre- and posttreatment linear measurements and angular measurements of molar tipping were evaluated with the *t*-test for paired samples. Multivariate analysis of variance (MANOVA) for repeated measures determined significant changes between groups. Further analyses with Bonferroni post hoc tests identified differences between groups upon MANOVA significance. All analyses were performed with the SPSS

Table 3. Mean Values at T1 and T2 and Expansion for All Linear Parameters[a]

Parameter	T1, mm (Mean ± SD)	T2, mm (Mean ± SD)	Δ (Expansion), mm (Mean ± SD)	*P* Value
BMW1M	56.7 ± 3.9	62.4 ± 4.4	5.6 ± 2.7	<.0001
PMW1M	29.0 ± 2.9	33.2 ± 3.7	4.2 ± 3.4	<.0001
BMW2P	51.8 ± 4.2	55.7 ± 4.5	3.9 ± 2.7	<.0001
PMW2P	25.6 ± 2.9	29.3 ± 3.7	3.7 ± 3.3	<.0001
BMW1P	45.2 ± 3.7	48.9 ± 3.9	3.7 ± 3.0	<.0001
PMW1P	20.2 ± 3.4	24.5 ± 3.8	4.3 ± 3.5	<.0001
BMWC	37.8 ± 3.5	39.9 ± 5.8	3.3 ± 3.2	.0413
DWC	21.4 ± 2.5	25.2 ± 3.1	3.8 ± 3.2	<.0001
DW1M	32.3 ± 3.6	39.2 ± 4.3	6.9 ± 3.4	<.0001

[a] See Table 2 for parameter designations.

Table 4. Mean Palatal Angle at T1 and T2 and Dental Tipping[a]

Palatal Angle (PA1M)	T1, ° (Mean ± SD)	T2, ° (Mean ± SD)	Δ, ° (Mean ± SD)	*P* Value
PA1M-r	107.4 ± 6.2	112.0 ± 6.2	4.6 ± 4.3	<.0001
PA1M-l	110.0 ± 7.6	114.0 ± 7.2	4.0 ± 5.2	.0003

[a] PA1M-r indicates palatal angle, right; PA1M-l, palatal angle, left.

Software, Version 22 (SPSS, Chicago, Ill; Figure 4) and Prism4, Version 4.0c (GraphPad Software, Inc).

RESULTS

The mean values for all T1 and T2 linear measurements and the difference (amount of expansion) are shown in Table 3. All parameters increased significantly between T1 and T2. For the buccal maxillary width (BMW), the expansion decreased from the 1M anteriorly to the C. For the palatal maxillary width (PMW), the greatest expansion was seen at the 1P. A trend toward greater expansion was observed in BMW for both the 1M and 2P compared to the increase in PMW. However, at the 1P level the reverse was true, as the PMW increased more than the BMW (Table 3; Figure 5A). In Table 4, statistically significant increases and great variability were noted for both the right (PA1M-r) and left (PA1M-l) palatal angles ($P < .001$).

Analysis of linear expansion relative to age (Figures 4 and 5) shows a statistically significant effect of age on expansion. More expansion was observed in the younger age group for all parameters, with the exception of the dental width canine (DWC), which increased more in the older subjects (Figures 4A and 5B,C). Analysis of the effect of age on molar tipping revealed a general trend for more tipping in older subjects (Figure 4B). Age had a significant effect on both the BMW and PMW expansion (Figure 5B,C; $P <$ .01 and $P < .05$, respectively), with more expansion occurring overall in the younger group. Greater buccal expansion occurred for both age groups at the 1M and decreased anteriorly. For palatal maxillary expansion, both age groups increased more at the 1P when compared to the 2P, with the younger group demonstrating a greater amount of expansion here even when compared to the 1M.

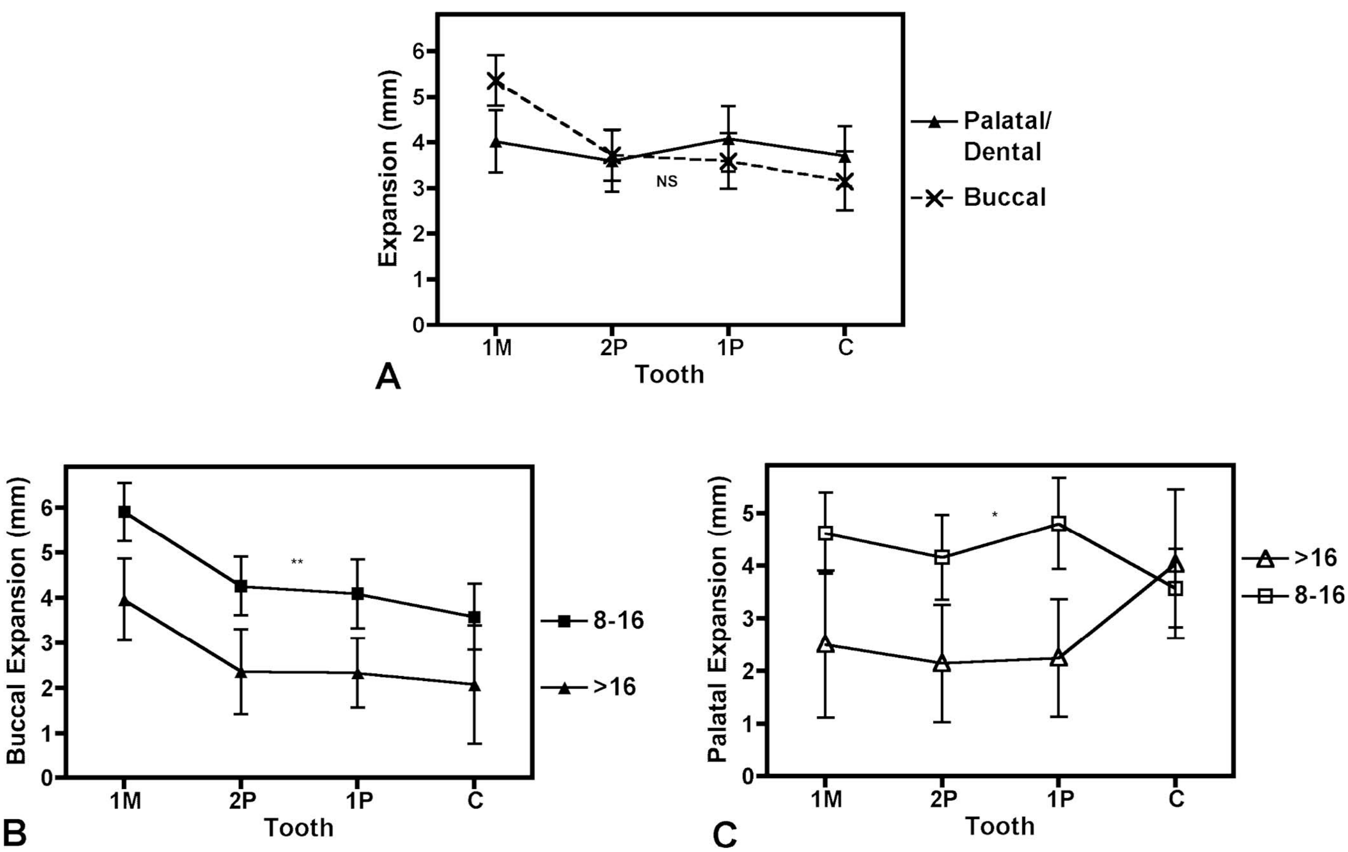


Figure 5. (A) Buccal vs palatal/dental expansion by location; (B) buccal expansion by age; (C) palatal/dental expansion by age (mean ± SE) (* $P < .05$; ** $P < .01$, NS indicates not significant, $P > .05$).

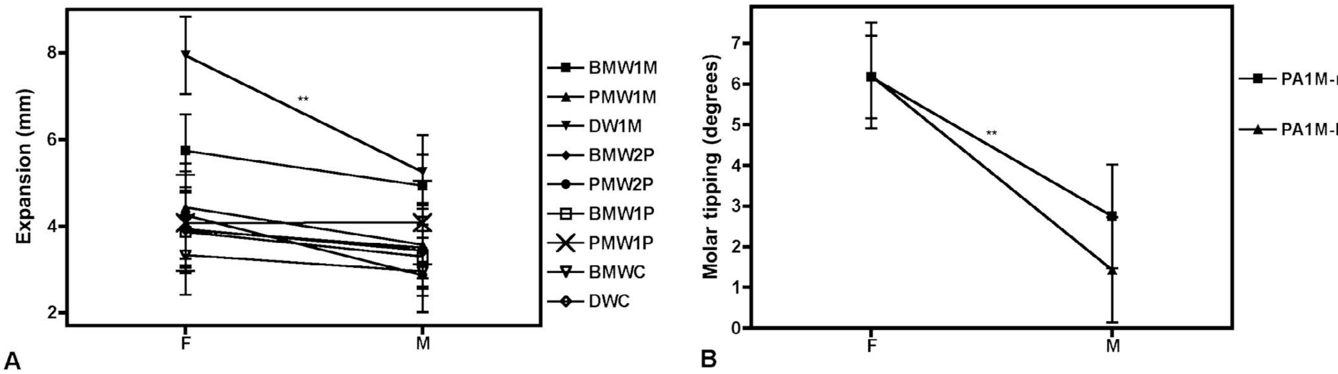


Figure 6. (A) Linear and (B) angular expansion by sex (abbreviations in Table 2) (mean ± SE) (** $P < .01$).

Sex had a significant impact on expansion (Figures 6A and 7), as males exhibited significantly less expansion for all parameters except PMW1P ($P < .01$). In Figure 6B, females showed significantly more dental tipping at both right and left molars than did the males ($P < .01$). Interestingly, additional analysis of dental tipping at each molar (Figure 8) revealed that some subjects demonstrated uprighting (a decrease in the PA). Figure 9A demonstrates that all but one of the instances of uprighting were found in the younger age group, and the molars that did upright were all in males (Figure 6B).

DISCUSSION

Previous studies have used CBCT to compare expansion from various RME appliances, including the hyrax expander,[10] banded vs bonded RMEs,[13] and Hass vs hyrax expanders.[2] However, no studies are available describing the effects of a rigid hyrax expander with the integration of TSADs. As a result of the abundance of maxillary sutural connections and the interactions of the dental complex with alveolar bone, isolation of the effects of RME into orthopedic and orthodontic components is difficult. Describing the effects of TSADRME relative to axial and coronal planes is a starting point for comparing orthopedic and orthodontic components.

Linear Expansion

Our findings support the effectiveness of the TSADRME in producing statistically and clinically significant dentoalveolar expansion. A model for the skeletal width pre- and posttreatment is shown in Figure 10. There was a greater increase in expansion for BMW compared with the PMW in the 1M and 2P area, a finding consistent with that of Garret et al.,[10] which was attributed to alveolar bending. However, in the present study this was not observed for the 1P, the only location in which the PMW increased more than the BMW. The location of the TSADs (Securus Ortho TAD, TOADS LLC, Louisville, Ky) in this area in the majority of subjects (N = 14, 56%), along with rigidity of the framework from 1P to TSAD, may have provided a more skeletally directed force vector, promoting less alveolar bending and more orthopedic expansion. This finding agrees with that of Lagravere, et al.,[12] who reported increased expansion at the 1P as the primary difference between a tooth-borne expansion group and a bone-anchored expansion group that may have been related to point of force application of the TSADs.

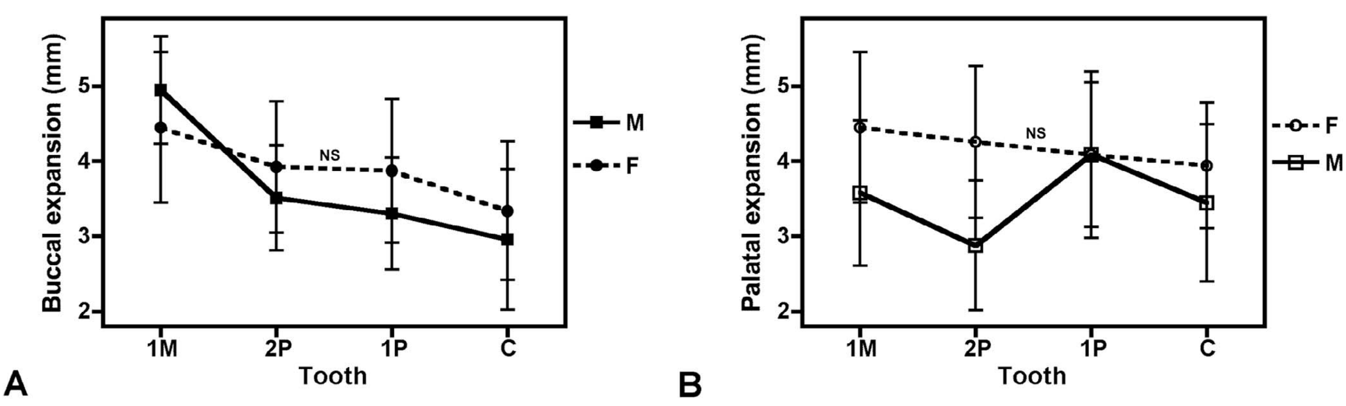


Figure 7. (A) Buccal and (B) palatal/dental expansion by location according to sex (mean ± SE) (NS indicates not significant, $P > .05$).

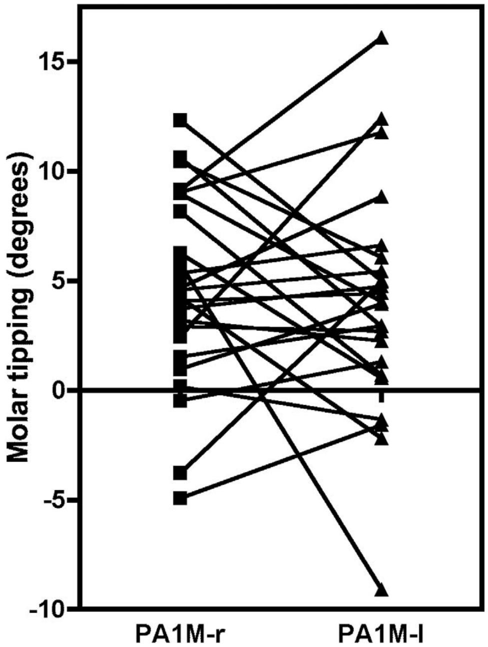


Figure 8. Palatal angle (molar tipping) between right and left first molar (PA1M-r and -l) by subject.

Molar Tipping

A clinically relevant proposed benefit of a rigid TSADRME is reduction of dental tipping, but accurate measurement in RME requires using a stable horizontal reference line. The superiority of CBCT over plaster cast analysis is the ability to visualize the total tooth relative to the reference plane. Previous CBCT studies have used the floor of the nasal cavity,[2] best-fit lines through the alveolar plate,[10] and the crista galli as this reference.[13] The use of structures proximal to and potentially affected by the device, such as the nasal floor, is not ideal, as the expansion itself may alter the orientation of these structures. Circum-maxillary sutures more distant from the maxilla have shown a lesser degree of disarticulation.[14] The use of a single point landmark (eg, crista galli), although distant from the maxillary complex and the area of active expansion, does not allow independent evaluation of the right and left molars. An ideal reference landmark should be a plane, rather than a point; the ideal landmark should also be reproducible, stable, bilateral, and located as far distant as possible from the expansion area. Our study proposes the use of a line tangent to the most inferior aspect of the skeletal orbits bilaterally as a reproducible landmark easily visualized in the coronal plane, allowing for independent evaluation of the right and left molars. A previous study[15] found a very small, clinically insignificant increase in aperture width and volume of the orbit after RME, but the location of this selected landmark at the base of the orbit is not appreciably affected by any slight increase in orbital volume or width. According to Iseri and Sollow,[16] the floor of the orbit is an area of apposition and resorption during long-term growth; however, these authors concluded that any errors incurred by superimposition on these structures would be minimal for a relatively short period of treatment (eg, 1 year). Although impossible to completely eliminate the effect of any changes in the maxillofacial complex due to growth in an actively growing population, our short mean interval of 7.8 months suggests the likelihood of minimal change at the orbital base.

Dental tipping appears to be a sequela of most appliances for RME, even for entirely bone-borne devices.[12] Our study found a mean molar tipping for the TSADRME of 4.31°, slightly less than that previously reported by Christi et al.,[17] Lagravere et al.,[12] and Weissheimer et al.[2] (a range of mean tipping of

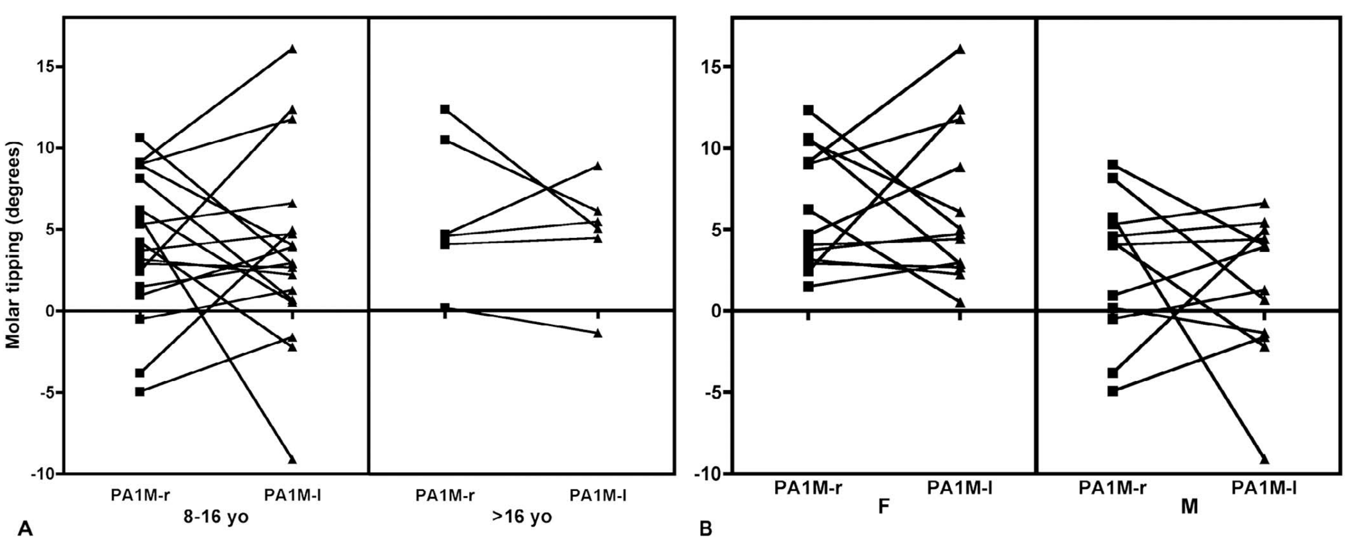


Figure 9. Palatal angle (molar tipping) between right and left first molar (PA1M-r and -l) by subject and age (A) and sex (B).

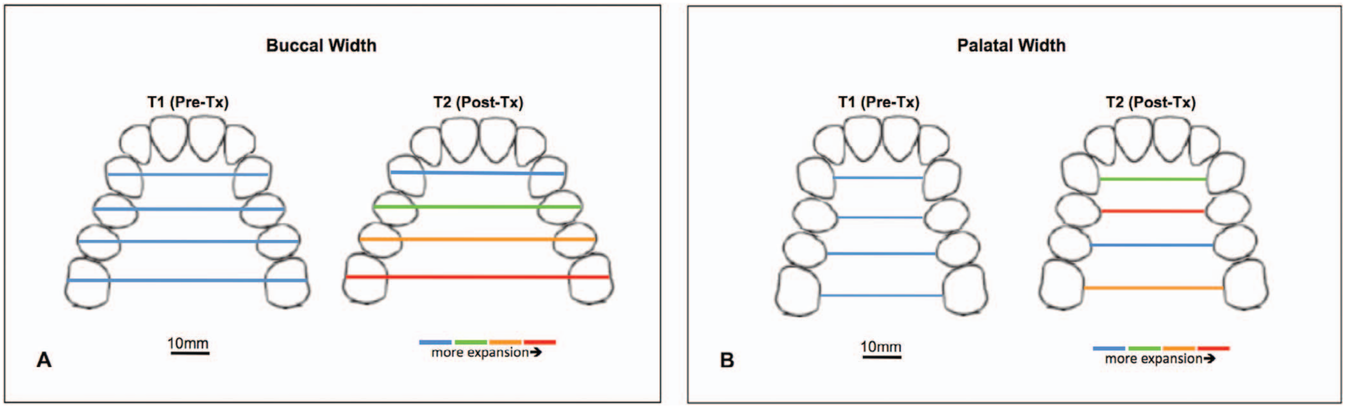


Figure 10. Model for the relative (A) buccal and (B) palatal skeletal dimensions pre- and posttreatment (T1-T2) with temporary skeletal anchorage device–supported rapid maxillary expansion appliance (TSADRME). Tooth outline represents the skeletal width.

5.91° to 6.87°), although these studies used different references for their measurements and may not be directly comparable. There was great variability among the subjects, between sexes, and between the right and left molars, consistent with the findings of Adkins et al.,[18] who observed variability in dental tipping but found no significant relationship with age, amount of expansion, or right or left molar.

Interestingly, in the present study, several subjects demonstrated mild uprighting of the molars during expansion, a finding not noted in most previous studies. Podesser et al.[19] did note mild uprighting of the 1M in some of their subject population; however, the mean age of this population was 8 years, 1 month, younger than our subjects' mean age. This finding of uprighting in the younger patients is consistent with the findings of our study, as almost all instances of uprighting occurred in the younger group.

The design of this appliance with the use of bands on the molar may provide some stabilization of the teeth in a buccolingual direction, which, coupled with a rigid connection to the TSADs, may minimize dental tipping, as was also proposed in a report of three cases by Kim and Helmkamp.[20] Further study is required with a larger subject population and/or incorporation of a direct comparison of a hyrax RME with the TSADRME in a controlled clinical setting to support or refute an increase in orthopedic expansion utilizing TSADs.

Effect of Age and Sex on Linear Expansion and Molar Tipping

The general observation that expansion may be related to age and skeletal maturity was supported by this study. Previous reports[21,22] suggest that interdigitation of the midpalatal suture increases with age and corresponding skeletal maturity, making sutural expansion more difficult. The older subjects in this study appeared to have more dental tipping, a finding to be expected if orthopedic expansion is limited by skeletal maturity and consistent with a comparison of dental tipping and age within four other studies.[2,12,17,19] The only parameter that increased less in the younger group was DWC, a finding probably associated with the typical eruption pattern of the canines or in response to the increase in available arch perimeter due to expansion.[18]

Females achieved significantly more expansion and exhibited more dental tipping. This may be related to the earlier occurrence of skeletal maturity in females resulting in a decreased orthopedic effect or related to the type or severity of malocclusion presented by the females in our population.

The TSADRME may provide more sutural opening in the area of the first molar and more relative palatal expansion in the area of the TSAD placement, but more studies are required, especially regarding the effect of the number and location of TSADs on dentoskeletal movement. A randomized prospective clinical study of age groups defined for skeletal maturation stage would allow direct comparison of the dentoskeletal effects of the traditional hyrax and the TSRADME.

CONCLUSIONS

- Our study suggests that the TSADRME appliance is a viable, clinically useful method of RME and offers a novel method by which to evaluate dental tipping using definable, consistent reference planes and landmarks.
- TSADRME results in mild dental tipping overall, but with great variability among subjects.

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