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Original Article

Effects of Rapid Maxillary Expansion on the Temporomandibular Joint: A Bone Scintigraphy Study

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Main Points

- An increase in metabolic activity occurs in the TMJ region during RME.
- The increase in metabolic activity in the TMJ region decreases over time following the RME procedure.
- Mandibular condyles have adapted over time to the forces exerted by RME in the region of theTMJ.

ABSTRACT

Objectives: The purpose of this study is to assess the effects of rapid maxillary expansion (RME) on metabolic activity in the temporomandibular joints (TMJs) of young adult patients using scintigraphy.

Methods: The images of the TMJs were obtained from the retrospective scintigraphic images taken from 17 adult females (between 16.1 and 18.8 years of age, mean age of 17.3 ± 0.86 years) who had non-functional bilateral posterior crossbite, deep palatal vault, and dental crowding, and had been treated with RME. Bone scintigraphs were collected at 3 time intervals: at the beginning of treatment (T1), during the opening of the mid-palatal suture (T2), and at the end of screw activation (T3). Alteration in bone activity in the TMJ regions were evaluated in sagittal and transaxial slices. To determine the differences between the intervals, repeated analysis of variance and Bonferroni multiple comparison tests were applied.

Results: In the right and left TMJ regions, significantly increased metabolic activity was exhibited between T1 and T2 ($P < .001$). At the time of opening the maxillary mid-palatal suture, the metabolic activity increased by approximately 60% compared to the initial status. At the end of the active expansion period (T3), the change in metabolic activity was approximately 20% lower compared to T2.

Conclusions: Metabolic activity intensified in the regions of interest in the TMJ during RME. After mid-palatal suture opening, the activity noticeably decreased (T2-T3). This decrease in bone activity suggests that the TMJ complex adapts to RME forces.

Keywords: Scintigraphy, maxillary expansion, temporomandibular joint, adaptive remodeling

INTRODUCTION

Rapid maxillary expansion (RME) is a treatment modality performed by heavy forces that can split the mid-palatal suture at a rate of 0.2-0.5 mm/day. RME is capable of effectively treating buccal crossbite and transversal maxillary deficiency. The 2 halves of the maxilla can be pushed reciprocally in young individuals during RME.[1] Although the precise purpose of RME is to treat maxillary arch deficiencies, its reactions are not restricted to the maxillary bone. Since the maxilla is related with 10 bones in the facial skeletal system, RME has the potential to affect directly or indirectly the structures that are associated with the maxilla, such as the mandible, nasal cavity,

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pharyngeal system, and the pterygoid process of the sphenoid bone.[2-4]

It has been shown that the major impediment to RME comes not only from the mid-palatal suture, but also from the other sutures of the maxilla and surrounding structures.[5] Of these neighboring structures, the zygomatic and sphenoid bones and the temporomandibular joint (TMJ) are particularly affected during RME.[6-8] Additionally, the rapid separation of the maxillary halves and the intensity of the forces applied to the jaw may cause functional loading and adaptive remodeling of the condyles, by altering the mandibular position and changing the occlusion.[9-11]

The effect of RME on TMJ has been considerably studied using traditional radiological imaging, cone beam computed tomography (CBCT), and magnetic resonance imaging (MRI) as diagnostic tools.[10,12,13] While CBCT is the chosen method for thorough analysis of alterations in TMJ skeletal structures, MRI is the preferred imaging modality for observing the soft tissues of the TMJ.[14] In a comprehensive literature review, Torres et al.[15] identified 3 significant findings about RME effects on TMJ. They showed that RME modifies the condyle-fossa relationship, does not modify the position or shape of the articular disc, and maintains intercondylar symmetry. However, neither CBCT nor MRI are adequate for early visualization of the effects of RME on the TMJ. Clinical studies using MRI have reported that the first mark of condylar remodeling is observed after 18 weeks of RME, but no information was provided about the duration of the expansion effect.[10] Following this pattern, it is accepted that in order for bone changes to be visible in radiography, there has to be approximately 30-50% demineralization.[16] Also, radiologic and other structural imaging modalities frequently fail to distinguish minor bone alterations. However, bone scintigraphy is capable of imaging skeletal metabolic activity and is commonly used to distinguish unusual vascularity or osteogenesis in the bone system, even if there is only an approximately 10% increase in osteoblastic activity above normal.[17] Due to its ability to detect metabolic changes, scintigraphy may be more illuminating, before noticeable structural changes appear on different radiographic methods.[18]

The questions that arise here are: How do condyles respond to functional and orthopedic forces of this magnitude? Does the high expansion force of RME influence the TMJ complex? If so, how long does the effect continue? Accordingly, in the present study, the early effects of the expansion procedure on TMJ were examined via scintigraphy. This paper aimed to extend and deepen this growing body of literature regarding the effects of RME on the TMJ by showing scintigraphic activation areas in the condyles depending on the stages of RME.

METHODS

The retrospective records of TMJ were obtained from the subjects who had participated in our 2006 study.[19] In the previous study, TMJ evaluation had not been planned, and the Clinical Research Ethics Committee's approval (decision number: 2018/23-19) was granted to conduct this retrospective study. Measurements were obtained from the images of the TMJ regions.

The records were collected from 17 skeletal Class I, normodivergent young adult females between the ages of 16.1 and 18.8 years (mean age: 17.3 $\pm$ 0.86 years). These patients had non-functional bilateral posterior crossbite, deep palatal vault, and dental narrowness, and they were treated with RME at the Department of Orthodontics, Faculty of Dentistry, Ataturk University.

The exclusion criteria were trauma, pathological orifice and jaw lesions, periodontal diseases, previous orthodontic treatment, and any evidence of TMJ disease. All potential benefits and risks were described to the patients and their families, and informed consent forms were signed. Only individuals who had a mid-palatal suture opening that was detected radiographically were included in the study. The skeletal maturation stage of all patients was 10-11, as reported by Fishman.[20] Biederman's RME appliance with a Hyrax screw (602-813, Dentaurum, Ispringen, Germany) was used, with an activation protocol of 2 times each day (0.5 mm) for an average of 20 days. Expansion was considered sufficient when the maxillary lingual cusp of the permanent first molar contacted the mandibular facial cusp of the permanent first molar.

99mTechnetium-Methylene Diphosphonate (99mTc-MDP) was used to obtain single-photon emission computed tomography (SPECT) images before RME (T1), during the splitting of the mid-palatal suture (T2), and at the end of screw activation (T3), to assess bone activity in the TMJ regions in each period. Patients were administrated an intravenous infusion of 0.4 mCi/kg (15 MBq/kg) 99mTc-MDP. Then, imaging was performed 3 hours after infusion of the radiotracer. The SPECT system was a single-headed gamma camera framework (GE 3200 XCT General Electric Medical System Ltd, St Albans, Herts, England) and images were taken with a low-energy, all-purpose, high-resolution collimator. In a 256 $\times$ 256 matrix, SPECT images were acquired for 25 seconds per frame over 360 rotations, with a 1.33 zoom. This produced 2 pixel-sized sagittal, transaxial and coronal images (Figures 1-4). Ten pixel-sized circular regions of interest (ROI) were marked on the medial slices of the sagittal and transaxial images.

Scintigraphic examinations can be affected by fluid intake, hunger–satiety situations, or general fitness.[21] To overcome this limitation, the relative uptake of 99mTc-MDP was calculated by dividing the activity counts on the TMJ regions by the background activity counts determined from the symphysis area. All results were stated as a mean ratio of uptake in the ROI to that of the sagittal and coronal mandibular symphysis. Since the condylar region and the zygomatic bone are superposed in the coronal plane, coronal measurements were calculated for only the symphysial area. In all slices, these quantitative assessments were executed using the Genie processing program (Genie, Version 2.6S, General Electric Medical System Ltd, Milwaukee, Wisconsin). To distinguish the accuracy of the selected TMJ regions and the reliability of positions, the scintigraphs were evaluated 3 times and the average values were considered.

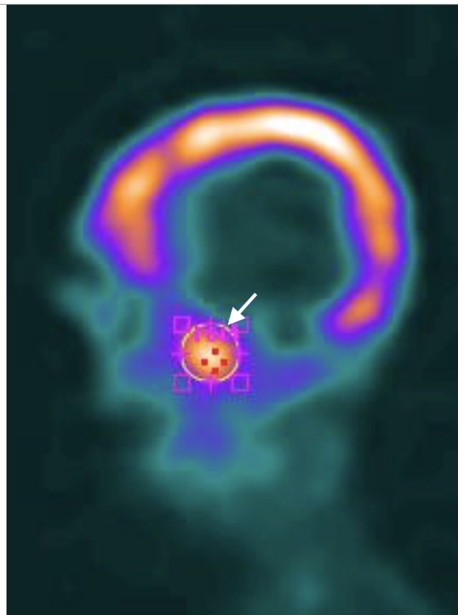

Figure 1. The regions of interest were examined on the sagittal slice of the left condyle (white arrow).

Statistical Analysis

All descriptive statistics were calculated for each interval. To compare the measurements after initial screening, repeated analysis of variance (ANOVA) and Bonferroni multiple comparison tests were executed, the *F* values of which were found to be statistically significant. Data management and analysis were performed using SPSS for Windows, Version 10.0 (SPSS Inc, Chicago, IL), and $P = .05$ was considered statistically significant. Post hoc power analysis was performed using the online ClinCalc Post Hoc power calculator (https://clincalc.com/stats/Power.aspx).

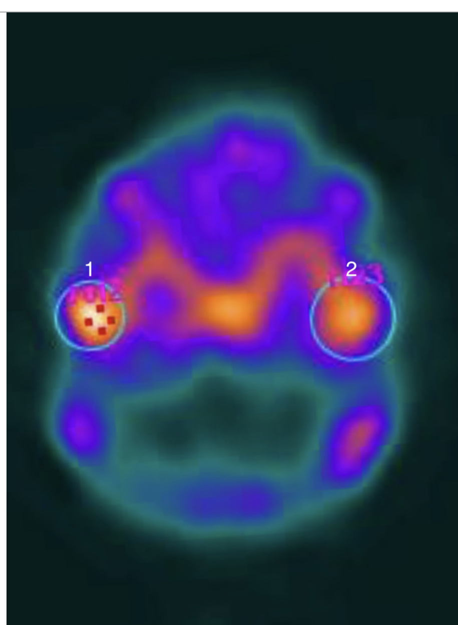

Figure 2. The regions of interest were examined on the transaxial slice of the condyles (A) Left condyle (B) Right condyle.

Figure 3. The regions of interest were examined on the sagittal slice of the symphysis area (white arrow).

RESULTS

The results of this study show that there was a condylar reaction to RME in young adult females. The descriptive statistics and ANOVA results are shown in Tables 1 and 2. Bonferroni multiple comparison test results are presented in Tables 3 and 4.

The right and left TMJ regions showed significant intensification of metabolic activity between the T1 and T2 periods. In the course of opening the maxillary mid-palatal suture (i.e., at the end of the 20-day-long active treatment), the metabolic

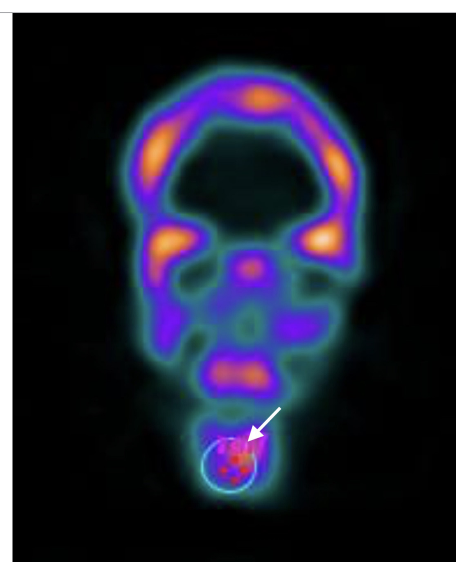

Figure 4. The regions of interest were examined on the coronal slice of the symphysis area (white arrow).

Table 1. Descriptive statistics and the results of the repeated measures analysis of variance (Sagittal Slice)

	T1		T2		T3		
N = 17	Mean	SD	Mean	SD	Mean	SD	*F*
Regions							
Right joint	0.53	0.13	0.86	0.25	0.75	0.10	28.52***
Left joint	0.60	0.15	0.89	0.21	0.75	0.10	23.67***

***$P < .001$.
SD, standard deviation.

Table 2. Descriptive statistics and the results of the repeated measures analysis of variance (Transaxial Slice)

	T1		T2		T3		
N = 17	Mean	SD	Mean	SD	Mean	SD	*F*
Regions							
Right joint	0.56	0.17	0.90	0.29	0.78	0.15	32.66***
Left joint	0.63	0.18	0.91	0.21	0.76	0.12	26.52***

***$P < .001$.
SD, standard deviation.

Table 3. The results of the bonferroni multiple comparison test (Sagittal Slice)

	T1-T2	T1-T3	T2-T3
Regions			
Right joint	−0.33***	−0.22***	0.11
Left joint	−0.29***	−0.14**	0.15*

*$P < .05$, **$P < .01$, ***$P < .001$.
SD, standard deviation.

Table 4. The results of the bonferroni multiple comparison test (Transaxial Slice)

	T1-T2	T1-T3	T2-T3
Regions			
Right joint	−0.34***	-0.22***	0.12*
Left joint	−0.27***	-0.13***	0.14**

*$P < .05$, **$P < .01$, ***$P < .001$.
SD, standard deviation.

activity increased by approximately 60% compared to the initial status. Metabolic activity decreased between the T2 and T3 periods. At the end of the active expansion (T3), metabolic activity intensification showed an approximately 20% reduction compared to T2, and this reduction was statistically significant. The difference between the values for metabolic activity between the first and last time points was still statistically significant (Tables 1-4).

In this study, post hoc power analysis was analyzed for collected data. The calculated power for the cellular activity detected varied by 92.9% and 100% between the measurements over time. The power calculated was largely above 80%, indicating that the sample size was reliable for this study.

DISCUSSION

The effects of RME on the TMJ complex are generally investigated using 2D radiological methods,[12] MRI,[10] and CBCT imaging. The development of CBCT, which offers lower-dose scanning and higher-resolution imaging, has created the opportunity to visualize the complicated hard tissue of TMJ. Thus, much of the literature on CBCT imaging of TMJ after RME has focused particularly on evaluating the condyle-fossa relationship spatially. Although there are studies which report that RME improves the relationship of asymmetric condyle-fossa in functional crossbite cases,[12] there are publications showing that it does not cause any change positionally in functional crossbite[22] or non-functional maxillary transversal deficiency cases.[13] Although MRI is considered to have the ability to visualize unmineralized soft tissue of the TMJ,[23] it is inadequate for early visualization of RME effects on the TMJ. Ruf and Pancherz[23] stated that the first sign of condylar remodeling is revealed by MRI after 6-12 weeks of Herbst treatment. Following this pattern, one well-known study of the effect of RME on the TMJ is an often-cited publication by Arat et al.[10] They reported that a sign of condylar remodeling is bone marrow edema seen in MRI in the 18th week of expansion, but they did not specify whether this was ineffective or detrimental. Thus, a question remains as to whether RME influences the condyles negatively or positively.

Bone scintigraphy studies have focused on the effects of functional orthopedic treatment (FOT) to the adaptive growth of condylar cartilage and bone responses to treatment,[24] or biomechanically generated bone activity in the neighboring tissues of mid-palatal suture during and after RME.[25] However, there is no useful information about the effects of RME on the TMJ area before structural changes are visible on radiographs. In the present study, given its ability to identify functional changes, we used scintigraphy imaging to measure bone activity of the TMJ area, which has not been investigated before. Also, scintigraphic studies of the TMJ in the literature focus on the imaging of changes in the sagittal direction of the condyle. However, our study is the first to evaluate transversal forces on the condyle.

In terms of functional treatment, a scintigraphic study by Paulsen et al.[24] reported that new bone formation was initiated by Herbst treatment in a patient who had an asymmetric mandibular condylar growth. Among the potential stimulatory mechanisms that cause adaptive remodeling is the muscle hypothesis, according to which the stimulation arises from lateral pterygoid muscle hyperactivity.[26] However, recent studies have indicated that the viscoelastic properties that are associated with protracted retrodiscal tissue, fibrous capsule, and the glenoid fossa provide adaptive remodeling of the condyle and glenoid fossa, rather than hyperactivity in muscles.[27] Importantly, the treatment mechanism of FOT differs significantly from RME. The FOT mechanism is very similar to a simulated joint between the maxilla and the mandible, and it positions the mandible in a protruded position by continuous (Herbst) or intermittent (activator) force. FOT improves occlusion by the simulation of growth at the mandibular condyle, protruding mandibular incisors, and distalizing maxillary molar teeth. To distalize molars, the adequate force ranges from approximately 150 g to 250 g.[20] Conversely, RME produces an interrupted force with levels ranging from 0.007 to 11.59 kg.[28] Thus, compared to FOT, RME's stress level is high, and the type of force is different. Moreover, Zimring and Isaacson[5] reported that reaction forces associated with maxillary suture expansion dissipate within the craniofacial skeleton at least 6 weeks after RME, but our study indicates that they start to dissipate within the median palatal suture splitting—within approximately 3 weeks.

One hypothesis for RME effects on the condyle is that RME forces lead to the mandible reposing itself further back, which can exert extra pressure from the condyle toward the glenoid fossa. Thus, the mandible is forced into establishing a different pattern, which alters functional condylar loading.[10] In a CBCT study of patients of ages similar to the group used in our study, McLeod et al.[13] reported that RME did not significantly affect condyle position in cases of non-functional maxillary narrowness. However, the fact that the position of the condyle did not change does not mean that the condyle was not subjected to compressive forces. In the present study, metabolic activity showed significant increase up to the splitting of the mid-palatal suture. After the opening of the mid-palatal suture, activity exhibited a remarkable decrease. The present study showed decreasing RME forces in the TMJ, from the early stages of expansion. Our findings can be interpreted as evidence that transversal or rotational forces caused cellular activity intensification in the condylar region from the early period of RME. The decrease in cellular activity after the end of the screw activation period shows that the condyles have adapted to the expanding forces immediately after the splitting of the mid-palatal suture, and the TMJ complex tends to return to normal situation. The TMJ region is an anatomically restricted area that is surrounded by glenoid fossa and fibers. It was assumed that if the pressure persisted, RME forces could damage the TMJ; however, the result of this basic investigation can help in understanding the effects of temporary pressure on the condylar region by showing that residual forces of RME do not affect TMJ regions for a long time.

Overall, although our study had some strengths, it also had limitations. First, when considering that patients reach their growth spurt at 12-13 years of age (females) or at 14-15 years of age (males),[29] and that the gain is skeletal in nature with RME before the peak in growth spurt, while it is more dentoalveolar in nature during or after the peak in growth spurt, it can be thought that the average age of selected samples in this study is high. However, this age group was selected because of the harmful effect of radiotracers, especially for children.[30] Moreover, only those patients whose mid-palatal suture opening had been seen radiographically were included in our study, and this disadvantage was ruled out. Meanwhile, this preference is also advantageous. Given that the radiotracer is taken up by the tissues intensely in childhood and the amount of radiotracer uptake diminishes with maturation,[18] if younger patients were included in the study, it would be difficult to determine whether the detected cellular activity in the TMJ originated from RME or young tissues with high cellular activity. Further, to perform the present study only on females was a reasonable choice. If both sexes had been included in the present study, it would have been complicated to determine whether the observed cellular activity originated from RME or from the tissues, at different stages of maturity in females and males. Second, in our study, the different screws and screw activation procedures were not compared. Considering the high residual loads of RME, future studies should assess the effects of RME on TMJ regions by examining other RME procedures with memory screws or with a slow maxillary expansion protocol that produces less tissue resistance.

CONCLUSION

The conclusions drawn from the present study can be summarized as below:

- The results of this study demonstrate a condylar reaction to RME.
- There was statistically significant increase in metabolic activity while splitting the mid-palatal suture. At the end of the active expansion, the increased metabolic activity showed a decreasing trend.
- Mandibular condyles adapt to transversal and rotational residual loads and tend to return to their normal condition shortly after mid-palatal suture opening.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Biruni University, (Approval No: 2018/23-19).

Informed Consent: Verbal informed consent was obtained from all participants who participated in this study.

Peer Review: Externally peer-reviewed.

Author Contributions: Concept - B.B., G.D.G.; Design - B.B., G.D.G.; Supervision - B.B.; Materials - B.B.; Data Collection and/or Processing - B.B., I.C., I.Y., I.M.D.; Analysis and/or Interpretation - H.U., M.F.; Literature Review - G.D.G., N.M.T.; Writing - G.D.G., N.M.T.; Critical Review - B.B.

Conflict of Interest: The authors have no conflict of interest to declare.

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