12-30-2019

Comparison of External Root Resorption in Orthodontic Treatment between Self-Ligating and Conventional Bracket Systems

Nuriah Bohari

Center of Studies for Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Universiti Teknologi MARA, Sungai Buloh, Selangor 47000, Malaysia

Noor Airin Koah

Center of Studies for Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Universiti Teknologi MARA, Sungai Buloh, Selangor 47000, Malaysia

Rohana Ahmad

Center of Studies for Restorative Dentistry, Faculty of Dentistry, Univerisiti Teknologi MARA, Sungai Buloh, Selangor 47000, Malaysia, drrohana@uitm.edu.my

Follow this and additional works at: <https://scholarhub.ui.ac.id/jdi>

Part of the [Dental Materials Commons](#), and the [Orthodontics and Orthodontology Commons](#)

Recommended Citation

Bohari, N., Koah, N. A., & Ahmad, R. Comparison of External Root Resorption in Orthodontic Treatment between Self-Ligating and Conventional Bracket Systems. J Dent Indones. 2019;26(3): 126-132

This Article is brought to you for free and open access by the Faculty of Dentistry at UI Scholars Hub. It has been accepted for inclusion in Journal of Dentistry Indonesia by an authorized editor of UI Scholars Hub.

ORIGINAL ARTICLE

Comparison of External Root Resorption in Orthodontic Treatment between Self-Ligating and Conventional Bracket Systems

Nuriah Bohari¹, Noor Airin Koay¹, Rohana Ahmad^{2,3}

¹*Center of Studies for Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Universiti Teknologi MARA, Sungai Buloh, Selangor 47000, Malaysia*

²*Center of Studies for Restorative Dentistry, Faculty of Dentistry, Universiti Teknologi MARA, Sungai Buloh, Selangor 47000, Malaysia*

³*Integrative Pharmacogenomic Institute, Universiti Teknologi MARA, Puncak Alam, Malaysia*
Correspondence e-mail to: drrohana@uitm.edu.my

ABSTRACT

The relationship between orthodontic bracket systems and external root resorption has remained debatable. **Objective:** This study compared the magnitude and pattern of the external root resorption of maxillary incisors as induced by self-ligating and conventional bracket systems via cone beam computed tomography and medical imaging programs. **Methods:** Eight participants were recruited for each bracket system. Their maxillary incisors were scanned at the beginning (T0) and 18 months into treatment (T1). Three-dimensional models of the four maxillary incisors at T0 and T1 were reconstructed using the Mimics program. The difference in root length between T0 and T1 models represented external root resorption. Wilcoxon signed rank and Mann–Whitney tests were conducted to compare resorption within groups and between groups, respectively. The two models were also superimposed in the 3-matic program to reveal the pattern and magnitude of resorption as induced by the different complexities of tooth movement. **Results:** The root resorption in both groups was significant. The mean root resorption of the conventional system ranged from 0.14 mm to 0.51 mm, whereas the mean root resorption of the self-ligating system varied from 0.16 mm to 0.42 mm, but the mean difference between the groups was not significant. However, the pattern and magnitude of root resorption noticeably differed when the teeth were subjected to different complexities of tooth movement. **Conclusion:** The magnitude and pattern of root resorption seemed independent of the type of bracket system used but appeared dependent on the complexity of tooth movement.

Key words: cone beam computed tomography, root resorption, self-ligating, STL superimposition

How to cite this article: Bohari N, Koay NA, Ahmad R. Comparison of external root resorption in orthodontic treatment between self-ligating and conventional bracket systems. *J Dent Indones.* 2019;26(3):126-132.

INTRODUCTION

External root resorption is a frequent iatrogenic orthodontic treatment consequence that results in an irreversible loss of a root surface and has received substantial interest from clinicians and researchers. Although resorption is typically minimal and considered clinically insignificant, severe resorption affects longevity, prognosis of the affected tooth, and continuity of orthodontic treatment. The maxillary anterior teeth are mostly affected in dentition, with an average resorption of 1.14 mm to 1.47 mm.¹ The etiology of external root resorption in orthodontically treated teeth is multifactorial and can be generally grouped as patient- and treatment-related factors.² Treatment-

related factors include treatment duration, magnitude of applied force, direction of tooth movement, amount of apical displacement, and type of appliance.³⁻⁷ However, findings about the effect of the type of appliance on root resorption are contradictory. Although self-ligating bracket systems result in reduced friction compared with that of conventional brackets and ultimately cause less root resorption.^{8,9} Some studies reported no mean difference in the degree of the root resorption of maxillary incisors between the two bracket systems.^{3,7}

Clinically, root resorption is detected in a two-dimensional (2D) manner by using periapical radiographs.

Although they are widely used as important diagnostic tools, varying degrees of magnification and foreshortening combined with the lack of repeatability may result in errors and inaccuracies when the actual degree of resorption occurring during or after orthodontic treatment is being observed and quantified.¹⁰ External root resorption is limited not only to the apex of the root but also to buccal and palatal sides, which cannot be captured by a periapical radiograph.¹¹ Hence, the use of a 3D radiography, such as cone beam computed tomography (CBCT), which can capture the entire image of a root, is required to accurately evaluate this 3D phenomenon.¹² With advances in CBCT having advantages of low radiation dose and improved accuracy, this technique is a feasible alternative to evaluate root resorption.¹³ It has a better ability to diagnose and detect simulated external root resorption than that of periapical radiographs.¹⁴ CBCT also demonstrates a high accuracy for root and tooth length measurement.¹⁵

The actual degree of root resorption can be misrepresented when this 3D phenomenon is quantified with 2D radiographs. Therefore, this study was undertaken to compare the magnitude and pattern of the root resorption of maxillary incisors when conventional and self-ligating preadjusted bracket systems were used in a 3D manner via CBCT and medical imaging. Another strength of this study was the relatively long-term evaluation of root resorption, which was measured 18 months into orthodontic treatment in comparison with that in other similar studies.¹⁶⁻¹⁹ The type of tooth movement in this study was different because cases with Class I bimaxillary proclination and Class II incisor relationships with the extraction of the first premolars were included, while other studies have included only nonextraction cases presented with Class I malocclusion.¹⁶⁻¹⁹

METHODS

This prospective clinical study involved 16 participants who attended Universiti Teknologi MARA Orthodontic Clinics, Malaysia. Ethical approval was obtained from the research and ethics committee of Universiti Teknologi MARA (600-RMI (5/1/6) 28/5/2015). The participants were divided into two equal groups. One group received a passive self-ligating bracket system (AO, Wisconsin, USA), and the other received a conventional pre-adjusted bracket system (AO, Wisconsin, USA) with 0.022 inch × 0.028 inch McLaughlin–Bennett–Trevisi (MBTTM) bracket slot. The treatment protocol was standardized with initial alignment and leveling phase with sequences of 0.012, 0.014, 0.016, and 0.018 inch × 0.025 inch nickel titanium archwires. This procedure was followed by a working archwire composed of 0.019 inch × 0.025 inch stainless steel archwires for space closure, finishing, and detailing.

Power analysis showed that a sample size of at least eight subjects for each group would give an 80% probability of detecting a real difference of 0.5 mm between groups at a statistically significant level of 5%. A possible difference of 0.5 mm between groups was selected on the basis of a previous study¹⁶, which examined the amount of root resorption through CBCT after 7 months of orthodontic treatment.

Inclusion criteria were bimaxillary proclination, Class I or Class II malocclusions that require the extraction of the first premolars, no previous history of orthodontic treatment, and good oral hygiene. Exclusion criteria included patients with a history of trauma to maxillary incisors, endodontically treated maxillary incisors, abnormal root shape, impacted teeth, cleft lip and palate, other syndromes, and asthma. Written consents were obtained from the volunteer participants.

The treatment protocol was standardized with initial alignment and leveling phase by using heat-activated nickel titanium archwires. This procedure was followed by a working archwire composed of 0.019 inch × 0.025 inch stainless steel archwires for space closure. CBCT scans were acquired at two time intervals, that is, before (T1) and 18 months after the initiation of orthodontic treatment (T2). All CBCT images were taken from one machine (CS9000 3D, Carestream Dental, Rochester, NY, USA) set at 80 kV, 8 mA, an FOV of 5 cm × 5 cm, and scanning time of 20 s to produce a voxel size of 90 μm × 90 μm × 90 μm. All images were reconstructed into 3D models by using the Mimics program (version 17.1; Materialise NV, Leuven Belgium) for root resorption assessment. For each patient, a threshold value that would produce a complete and smooth structure of the four maxillary incisors without too many artifacts or deficiencies was selected. The selected thresholding value varied between patients because their teeth differed in density. Similar threshold values were individually chosen for the 3D model calculation to ensure that the reconstruction of the teeth was of the same dimension. Hence, any changes between the 3D models would be the result of root resorption and not of different thresholding values.

Manual segmentation was also carried out to remove artifacts due to beam hardening as a result of the presence of metal brackets and wires. The models were also smoothed with a standardized smoothing parameter used for before and after 18 months of treatment so that any changes in length/dimension were due to root resorption and not the different parameters of smoothing used. Root length was measured from the apex of the root marked A to the middle of the crown tip marked B (Figure 1). The model was carefully scanned to ensure that the root and crown tips were correctly located. The difference in root length before and 18 months into the treatment was taken as root resorption.

Figure 1. Measurement of root length on a 3D model of a central incisor from the apex of the root to the middle of the crown tip. a, Palatal view; b, mesial view. A, Root apex and B, middle of crown tip.

The 3D models of the teeth at time points T1 and T2 were superimposed individually in the Mimics program by using a standard tessellation-based superimposition technique to visualize root resorption patterns.²⁰ Thereafter, the superimposed models were exported to a Materialise 3-matic program (Materialise NV, Leuven Belgium, version 8.0) for color mapping analyzes to reveal the areas and depth of root resorption and deposition.

Statistical Analyses

Ten images were re-measured at an interval of 2 weeks to ensure consistency in the measurement of root length. Intraclass correlation coefficients (ICCs) were used to assess the intra-observer reliability. IBM SPSS Statistics version 23.0 was used for data analysis, and significance level was set at $P < 0.05$. Given that data distributions were not normal, a Wilcoxon signed rank test was conducted to determine the significance of root resorption within each group, and a Mann–Whitney test was performed to compare root resorption between the two bracket systems.

RESULTS

Magnitude of root resorption

The mean ages of the subjects in the self-ligating bracket group and the conventional bracket system were 24 ± 3.3 years (5 females, 3 males) and 20 ± 3.0 years (4 females, 4 males), respectively. For all root length measurements, the ICC of the reliability was greater than 0.80. Table 1 shows the amount of the root resorption of the maxillary incisors for conventional and self-ligating brackets.

Wilcoxon signed rank test revealed that root resorption was statistically significant ($P < 0.05$) for all incisors within each group. However, when Mann–Whitney test

was used to compare the magnitude of root resorption between the two bracket systems, the difference was not significant (Table 2).

Given that the bracket system did not seem to affect the magnitude of root resorption, other factors, such as the complexity of tooth movement, should be examined. For this purpose, the participant whose incisor on one side had good alignment and the tooth on the contralateral side had poor alignment was chosen for discussion. In particular, the subjects labeled 2 from the conventional bracket group and labeled 5 from the self-ligating group were selected (Table 1). The magnitude and pattern of the root resorption of these two subjects were discussed in detail. We would like to emphasize here that we evaluated each incisor, but we reported these two cases only because they showed the highest degree of difference in root resorption within the same individual. However, the results should be interpreted cautiously because more cases with this unique character and findings should be investigated further.

Root Resorption Pattern

Figure 2 depicts the intraoral maxillary occlusal photos of subject 2 at T1 and T2 to compare the dissimilarity in the positions of maxillary right and left lateral incisors. The maxillary right lateral incisor was slightly extruded and palatally displaced, and its root was more palatally positioned than the crown. The treatment started with an insertion of a transpalatal arch on the first permanent molars and followed by the extraction of all first premolars. The canines were then retracted to Class 1, and a space was created for the right lateral incisor by using a push coil between the right canine and the central incisor. The maxillary right lateral incisor was intruded and derotated, and the apex moved labially through the inverted bracket placement to improve its position and alignment. The maxillary left lateral incisor had an acceptable alignment in the arch and therefore needed only simple movement during orthodontic treatment. Thus, the right lateral incisor had a severe root resorption of 1.87 mm compared with that of the left lateral incisor with a resorption magnitude of only 0.38 mm. The 3D root superimposition models demonstrated that the root resorption activity of the right lateral incisor was greater on several root surfaces, including the apex, labial, and mesial surfaces, than on other surfaces. By contrast, the root resorption activity of the left lateral incisor was confined to the distal part of the root surface. The red and green areas of the root on the superimposed 3D models (Figures 2C and 2D) represented resorption and deposition, respectively.

Figure 3 illustrates the clinical case of subject 5 from the self-ligating group. The maxillary left lateral incisor was in the anterior crossbite, retroclined, and slightly extruded, and its root apex was more palatally positioned than the crown. The maxillary right lateral

Table 1. Magnitude (in mm) of the root resorption of the maxillary incisors in conventional and self-ligating bracket systems

Patient ID	Conventional Bracket				Self-ligating bracket			
	Root resorption (mm) of Maxillary Incisors				Root resorption (mm) of Maxillary Incisors			
	RL	RC	LC	LL	RL	RC	LC	LL
1	-0.26	-0.45	-0.03	-0.04	-0.47	-0.08	-0.04	-0.24
2	-1.87	-0.7	0.1	-0.38	-0.27	-1.07	-0.2	-0.34
3	-0.29	-0.11	-0.4	-0.3	-0.1	-0.16	-0.2	-1.19
4	0.1	0.02	-1.92	-0.05	-0.04	-0.07	-0.13	-0.04
5	0.03	-0.17	-0.52	-0.18	-0.08	-0.04	-0.2	-2.24
6	-0.52	-0.48	-0.45	-0.4	0.01	-0.09	-0.33	0.09
7	-0.11	-0.15	-0.02	-0.17	-0.03	-0.48	-0.79	-0.12
8	-0.24	-0.22	-0.06	-0.07	-0.15	-0.69	-0.51	-0.06
Mean (SD)	-0.39 (0.63)	-0.28 (0.24)	-0.47 (0.66)	-0.20 (0.15)	-0.14 (0.16)	-0.24 (0.38)	-0.30 (0.24)	-0.52 (0.80)

(RL–right lateral, RC–right central, LC–left central, LL–left lateral)

Table 2. Comparison of the difference in the median root resorption (mm) between self-ligating and conventional brackets

Maxillary Incisor	Self-ligating bracket (Median IQR)	Conventional bracket (Median IQR)	Z statistic	P Value
Right lateral (12)	0.09	0.25	-.840	0.401 NS
Right central (11)	0.12	0.19	-.368	0.713 NS
Left central (21)	0.20	0.23	-.421	0.674 NS
Left lateral (22)	0.18	0.17	-.053	0.958 NS

NS indicates no statistically significant difference

Figure 2. Comparison of the magnitude and pattern of the root resorption between the maxillary right and left lateral incisors of Patient ID No. 2 in the conventional bracket group. A. Pretreatment photo shows that the right lateral incisor was palatally displaced and extruded, and the left lateral incisor had better alignment in the arch. B. Eighteen-month treatment photo illustrates that the right and left lateral incisors had better alignment in the arch. C. The pattern of the root resorption of the right lateral incisor (mesial view) presents the predominant resorption at the apex of the tooth compared with D, and the pattern of the root resorption of the left lateral incisor (mesial view) reveals much less resorption. Green indicates the varying degrees of root deposition (from 0 mm to +2.0 mm), and red denotes root resorption (from 0 mm to -2.0 mm).

Figure 3. Comparison of the magnitude and pattern of the root resorption between the maxillary right and left lateral incisors of Patient ID No. 5 in the self-ligating bracket group. A. Pretreatment photo shows that the left lateral incisor was in the crossbite, extruded, and retroclined, and its root apex was palatally positioned. The right lateral incisor was proclined and rotated mesiolabially, but the root apex was in a normal position. B. Eighteen-month treatment photo illustrates that the maxillary right and left lateral incisors had better alignment in the arch. C. The pattern of the root resorption of the left lateral incisor (mesial view) presents the predominant resorption at the apex and on the buccal and palatal parts of the tooth compared with D, and the pattern of the root resorption of the right lateral incisor (mesial view) shows minimal resorption. Green indicates the varying degrees of root deposition (from 0 mm to +2.0 mm), and red denotes root resorption (from 0 mm to -2.0 mm).

incisor had mesiolabial rotation with a normal root position that only needed simple tooth movement. Multiple forces were applied to the left lateral incisor to improve the overjet, derotation, and forward movement of the root apex. The inverted bracket placement on the tooth resulted in a 20° labial root torque to bring the apex forward and to align the tooth in the arch. Consequently, the left lateral incisor had a higher root resorption of 2.24 mm than that of the right lateral incisor with only 0.08 mm resorption. The 3D root superimposition models (Figures 3C and 3D) revealed that the left lateral incisor showed a considerable root resorption activity, especially on the apex and labial surfaces of the root. By contrast, the right lateral incisor had a minimal root resorption activity that occurred only on a small part on the labial surface of the root.

DISCUSSION

In this study, the magnitude and pattern of the root resorption of the maxillary incisors between the conventional and self-ligating pre-adjusted bracket systems were compared in a 3D manner through CBCT and medical imaging, and the results did not significantly differ. The CBCT images and Mimics were used to create the 3D models and ensure that the true length of the tooth from the root apex to the tip of the crown was obtained. Length was measured from a selected point at the apex of the root to a point located at the center of the incisal edge. Although other similar studies have used CBCT for root resorption measurement^{16-17,21}, a 2D method is often selected to measure root length.^{7,10-11,22,23} Hence, the actual length of the tooth may have been misrepresented because the entire length of a tooth may not appear on one slice of a 2D sagittal view panel and may not coincide with the midline of the tooth. Furthermore, we may experience difficulty in ensuring that the same point of landmark is used for the measurement of the length of the tooth on the other set of CBCT image slices. By contrast, visualization was greatly enhanced using 3D tooth models as performed in this study, and the exact points of landmark were selected for the measurement of tooth length for both time points. Therefore, the resultant root resorption measured could be taken as being more accurate and contribute reliable evidence needed to conclude that self-ligating brackets do not cause a less degree of root resorption than conventional brackets do.

Using Mimics allows 3D models at two time points to be superimposed. This capability can be exploited to visualize the depth of resorption and deposition on the external surface. Using CBCT also enables the visualization of the root resorption pattern (Figures 2 and 3) that occurs at the periapical area, where it is most predominant, and on other root surfaces. Hence, orthodontic treatment may cause changes in root length and its overall dimension. Some areas of the root resorbed, while root deposition occurred in

other areas. Root resorption and deposition tended to occur on the compression and tension sides of the root, respectively. This observation was consistent with the findings of Chan and Darendeliler.²⁴ Therefore, the measurement of the changes in root length revealed a positive value in few cases in this study, and this value could be attributed to this root remodeling phenomenon and was not a measurement error. The more complex the type of tooth movement and the greater the distance of tooth movement were, the greater the root surface remodeling would be. The more severe root resorption was associated with a larger tooth movement, and this finding was also reported by Yu et al.¹⁶ Changes in tooth volume would be a better parameter to quantify root dimensional changes rather than changes in tooth length. However, the change in volume was not measured, so it was considered the main limitation of this study because of the difficulties in removing the beam hardening artifacts from the brackets on the crown part of the tooth and standardizing the curved cutting plane (for separating the crown from the root). The external root resorption was significant in both bracket systems in this study, but the external root resorption of one system was not significantly different from that of the other. Other studies have reported the same findings.^{10,17} The degree of root resorption in our study was quite similar to that in a CBCT study by Leite et al, who also compared conventional and self-ligating brackets.¹⁷ In our study, the interval between the first and second measurements of root length was 18 months, which was quite longer than that in other studies that usually measure root resorption after 6, 7, and 12 months.¹⁶⁻¹⁸ The measurement in our study was initially planned to be performed three times, that is, at pretreatment, 6 months, and 18 months into the orthodontic treatment. The measurement was planned to be carried out after 6 months because root resorption mostly occurs during this period.^{18,25} At 18 months, we would like to observe if further resorption occurred at this time. However, considering that radiation is associated with CBCT, the ethical committee of UiTM only allowed us to take CBCT at pretreatment and 18 months to reduce the amount of radiation by decreasing the frequency and increasing the interval between scans.

The mean root resorption values of the self-ligating and conventional bracket groups ranged from 0.16 mm to 0.42 mm and from 0.14 mm to 0.51 mm, respectively. These values were slightly similar to those from another study that used CBCT to measure root resorption, even though root resorption was measured later in our study, that is, after 18 months of orthodontic treatment initiation versus 6 months in the study of Leite et al.¹⁷ Aras et al. 2018 reported no volumetric difference in terms of external root resorption in the maxillary incisor teeth between conventional and self-ligating bracket systems 9 months into orthodontic treatment.¹⁹ This finding could confirm that root resorption mostly occurred within the first 6 months of orthodontic treatment.

In our study, we included patients with Class I bimaxillary proclination and Class II and III incisor relationships that required the extraction of the first premolars. This condition was different from previous studies, which selected nonextraction cases presented with Class I malocclusion.^{7,17,26} With the extraction of maxillary first premolars, the degree of incisor retraction was considerably larger than that in nonextraction cases. Although previous studies reported that the increased overjet and the increased degree of anterior tooth retraction are weakly correlated with larger maxillary anterior tooth root resorption, our study found an average of 0.29 mm to 0.33 mm maxillary anterior tooth root resorption.^{1,5} This value was similar to that obtained by Leite et al., that is, an average of 0.35 mm root resorption.¹⁷ Tieu et al. 2014 conducted a systematic review and observed that different treatment techniques in Class II malocclusions generally produce a similar degree of root resorption to that reported for other malocclusion types.²⁷ Therefore, the findings of this systematic review concurred with our results.

Tsichlaki et al. also performed a systematic review and observed that the average duration of a comprehensive orthodontic treatment is 20 months.²⁸ Although Makedonas et al. in 2012 reported no correlation between the mean treatment duration of 20.9 months and the degree of root resorption via a 3D study, Segal et al., who conducted a meta-analysis based on 2D data, demonstrated that a longer course of treatment (mean = 21.6 months) may cause a higher degree of root resorption.^{6,29-31}

The use of a small FOV CBCT as in this study may have exposed a patient to a slightly higher radiation than that of the use of a periapical radiograph (100 μ Sv versus 10 μ Sv) and may be considered a disadvantage. However, this additional exposure of 100 μ Sv is a small 3% increment to the annual radiation exposure of about 3000 μ Sv that we receive from our surroundings and may be considered negligible. Hence, the Research Ethics Committee of UiTM considered that the benefits of this study outweigh the disadvantages associated with a slight increase in radiation exposure and granted ethical approval. However, the authors do not recommend the routine use of CBCT to diagnose external root resorption.

CONCLUSION

Within the limit of this study, the type of brackets, either self-ligating or conventional, did not seem to have any effect on the magnitude and pattern of root resorption. The magnitude of root resorption was likely dependent on the complexity of tooth movement and the distance traveled by the root. Root resorption mostly occurred at the compressed surface of roots.

ACKNOWLEDGMENT

This study was funded by Universiti Teknologi MARA and REI grant (UiTM 600-RMI/DANA 5/3 REI [11/2015]).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1. Picanço GV, Freitas KMS, Cançado RH, Valarelli FP, Picanço PRB, Feijão CP. Predisposing factors to severe external root resorption associated to orthodontic treatment. *Dental Press J Orthod*. 2013;18(1):110-20.
2. Weltman B, Vig KW, Fields HW, Shanker S, Kaizar EE. Root resorption associated with orthodontic tooth movement: a systematic review. *Am J Orthod Dentofacial Orthop*. 2010;137:462-76.
3. Jacobs C, Gebhardt PF, Jacobs V, Hechtner M, Meila D, Wehrbein H. *Head Face Med*. 2014;10:2-7.
4. Chan E, Darendeliler MA. Physical properties of root cementum: Part 5. Volumetric analysis of root resorption craters after application of light and heavy orthodontic forces. *Am J Orthod Dentofacial Orthop*. 2005;127:186-95.
5. Dindaroğlu F, Doğan S. Root Resorption in Orthodontics. *Turk J Orthod*. 2016;29(4):103-s8.
6. Segal G, Schiffman P, Tuncay O. Meta-analysis of the treatment related factors of external apical root resorption. *Orthod Craniofac Res*. 2004;7:71-8.
7. Pandis N, Nasika M, Polychronopoulou A, Eliades T. External apical root resorption in patients treated with conventional and self-ligating brackets. *Am J Orthod Dentofacial Orthop*. 2008;134:646-51.
8. Damon DH. The rationale, evolution and clinical application of the self-ligating bracket. *Clin Orthod Res*. 1998;1:52-61.
9. Harradine NWT. Self-ligating brackets: where are we now? *J Orthod*. 2003;30:262-73.
10. Celikten B, Uzuntas CF, Kurt H. Multiple idiopathic external and internal resorption: Case report with cone-beam computed tomography findings. *Imaging Sci Dent*. 2014;44:315-20.
11. Jaju PJ, Jaju SP. Clinical utility of dental cone-beam computed tomography: current perspectives. *Clin Cosmet Investig Dent*. 2014;6:29-43.
12. Chan EKM, Darendeliler MA. Exploring the third dimension in root resorption. *Orthod Craniofac Res*. 2004;7:64-70.
13. Yi J, Sun Y, Li Y, Li C, Li X, Zhao Z. Cone-beam computed tomography versus periapical radiograph for diagnosing external root resorption: A systematic review and meta-analysis. *Angle*

- Orthod. 2017; 87:328-37.
14. Durack C, Patel S, Davies J, Wilson R, Mannocci F. Diagnostic accuracy of small volume cone beam computed tomography and intraoral periapical radiography for the detection of simulated external inflammatory root resorption. *Int Endod J.* 2011; 44:136-47.
15. Sherrard JF, Emile Rossouw P, Benson BW, Carrillo R, Buschang PH. Accuracy and reliability of tooth and root lengths measured on cone-beam computed tomographs. *Am J Orthod Dentofacial Orthop.* 2010;137:S100-8.
16. Yu JH, Shu KW, Tsai MT, Hsu JT, Chang HW, Tung K L. A cone-beam computed tomography study of orthodontic apical root resorption. *J Dent Sci.* 2013;8:74-9.
17. Leite V, Conti AC, Navarro R, Almeida M, Oltramari-Navarro P, Almeida R. Comparison of root resorption between self-ligating and conventional preadjusted brackets using cone beam computed tomography. *Angle Orthod.* 2012; 82:1078-82.
18. Artun J, Smale I, Behbehani F, Doppel D, Van't Hof M, Kuijpers-Jagtman AM. Apical root resorption six and 12 months after initiation of fixed orthodontic appliance therapy. *Angle Orthod.* 2005;75:919-26.
19. Aras I, Unal I, Huniler G, Aras A. Root resorption due to orthodontic treatment using self-ligating and conventional brackets. A cone-beam computed tomography study. *J Orofac Orthop.* 2018;79: 181-90.
20. Ahmad R, Abu-Hassan MI, Li Q, Swain MV. Three dimensional quantification of mandibular bone remodeling using standard tessellation language registration based superimposition. *Clin Oral Implants Res.* 2013;24:1273-79.
21. Lund H, Gröndahl K, Hansen K, Gröndahl HG. Apical root resorption during orthodontic treatment. A prospective study using cone beam CT. *Angle Orthod.* 2012;82:480-7.
22. McNab S, Battistutta D, Taverne A, Symons A. External root resorption following orthodontic treatment. *Angle Orthod.* 2000;70:227-32.
23. Adarsh K, Sharma P, Juneja A. Accuracy and reliability of tooth length measurements on conventional and CBCT images: An in vitro comparative study. *J Orthod Sci.* 2018;6:7-17.
24. Chan E, Darendeliler MA. Physical properties of root cementum: part 7. Extent of root resorption under areas of compression and tension. *Am J Orthod Dentofacial Orthop.* 2006;129:504-10.
25. Apajalahti S, Peltonen JS. Apical root resorption after orthodontic treatment - a retrospective study. *Eur J Orthod.* 2007;29:408-12.
26. Alexander, SA. Levels of root resorption associated with continuous arch and sectional arch mechanics. *Am J Orthod Dentofacial Orthop.* 1996;110:321-4.
27. Tieu LD, Saltaji H, Normando D, Flores-Mir C. Radiologically determined orthodontically induced external apical root resorption in incisors after non-surgical orthodontic treatment of Class II division 1 malocclusion: a systematic review. *Prog Orthod.* 2014;15:48
28. Tsihlaki A, Chin SY, Pandis N, Fleming PS. How long does treatment with fixed orthodontic appliances last? A systematic review. *Am J Orthod Dentofacial Orthop.* 2016;149:308-18.
29. Makedonas D, Lund H, Hansen K. Root resorption diagnosed with cone beam computed tomography after 6 months and at the end of orthodontic treatment with fixed appliances. *Angle Orthod.* 2013;83:389-93.
30. Baumrind S, Korn EL, Boyd RL. Apical root resorption in orthodontically treated adults. *Am J Orthod Dentofacial Orthop.* 1996;110:311-20.
31. Brin I, Tulloch JF, Koroluk L, Philips C. External apical root resorption in class II malocclusion: a retrospective review of 1- versus 2-phase treatment. *Am J Orthod Dentofacial Orthop.* 2003; 124:151-6.

(Received September 10, 2019; Accepted November 3, 2019)