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Original article

Evaluation of orthodontically induced root resorption using con-beam computed tomography and micro computed tomography

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ABSTRACT

Objectives: The present study was conducted to propose up a technique for evaluation of OITRR in bicuspids as evaluated by con-beam computed tomography (CBCT) and micro computed tomography Micro CT).

Methods: Ten healthy maxillary first premolars were extracted from eight adolescent healthy patients. Five of the premolars were removed prior to application of any orthodontic forces (group 1 control group), and the other five premolars were indicated to be removed in non– extraction orthodontic treated cases after a year due to change in their treatment plan to extraction of these five premolars (group 2 treatment group). All patients had initial CBCT as part of their initial treatment records and all extracted teeth were scanned using a micro-computed tomography (Micro CT) scanner. Reconstructed scanned images were processed and numerous crucial resorption lacunae parameters were evaluated including linear measurements of the width and length of the resorption lacunae. Comparisons were performed between the two groups initial teeth lengths (measured from CBCT and MicroCT).

Results: Orthodontic treatment caused the formation of considerably large tooth root resorption lacunae measured in length and breadth along the length of the root that were extracted after been moved orthodontically compared to those who were not moved orthodontically ($P < 0.05$). They were also observed in dentin areas for demineralization adjacent to the resorption lacunae.

Conclusion: The present study presented a standardized method to assess root resorption based on Micro CT.

1. Introduction

The orthodontically induced tooth root resorption (OITRR) is a pathological condition that occurs as a consequence of orthodontic treatment which leads to partial or complete loss of dental tissues permanently (Weltman et al., 2010). The etiology of root resorption can be classified as natural, pathological, and iatrogenic. OITRR is classified as root resorption of iatrogenic origin as it is caused by orthodontic forces. This resorption is inflammatory in the type wherein there is inflammation of the periodontal ligament that leads to the death of cementoblasts and triggers the formation of cementoclasts and odontoclasts. These cells cause resorption to prevent alveolodental ankylosis. Endodontic treatment interferes in tooth resorption induced by inflammatory processes caused by bacteria in the root canal and/or dentin tubules (Consolaro and Furquim, 2014). The microbial flora persists longer within the chronic inflammatory periapical diseases, such as chronic apical periodontitis or periapical granuloma etc. This is because the bacteria are allowed to form biofilms and colonize within the dentinal tubules, isthmus, lateral canals and the external part of the apical surface (Wang et al., 2020; Noori et al., 2012, 2013; Ansari et al., 2013, 2016). Malmgren et al. (1982) established a grading system for orthodontically induced root resorption (Malmgren et al., 1982).

Orthodontic force application initiates a sequential cellular process (Kasacka et al., 2006). It involves hyaline zone elimination process, during which the nearby outer surfaces of the root are damaged, thus exposing the underlying cementum. The root surface under the main hyaline zone is being resorbed by osteoclasts, which allows tooth movement, while the repair process involving osteoblasts at the periphery is already taking place. The resorption process continues until either no hyaline tissue is present or the force level decreases (Kaczor-Urbanowicz et al., 2017).

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Additionally, orthodontic tooth movement causes the occurrence of inflammatory process in the periodontium. Inflammatory mediators such as prostaglandins, interleukins, the tumor necrosis factor-α superfamily, and receptor activator of nuclear factor (RANK)/RANK ligand (RANKL)/osteoprotegerin (OPG) are increased in the PDL during orthodontic tooth movement (Vandevska-Radunovic, 1999). The presence of these inflammatory mediators in the PDL during orthodontic tooth movement indicates their role in the occurrence of orthodontically induced tooth root resorption (Yamaguchi and Fukasawa, 2021).

The contributing factors associated with OITRR can be classified into 2 types. One is the patient associated risk factors which can also be called biological factors and the other is orthodontic treatment-related risk factors also called as mechanical factors (Topkara et al., 2012). The biological factors include root morphology, tooth agenesis, asthma, diabetes, and habits like nail-biting. The associated mechanical factors are magnitude of orthodontic forces, the type of tooth movement, duration of the treatment and type of forces applied. The periodontal ligament plays a vital role in root resorption by regulating the differentiation of odontoclasts. Periodontal ligament stem cells (PDLSCs), which were isolated from periodontal tissue, are capable of differentiating into osteoblast, adipocyte, and tooth cementoblast in vitro and regenerating cementum/PDL tissue in vivo (Hasegawa et al., 2002; Li et al., 2014; Seo et al., 2004).

OITRR can be diagnosed by panoramic radiographs, periapical radiographs, Cone Beam Computed Tomography (CBCT). CBCT imaging allows radiation to be focused on the area of anatomical interest, while encompassing all hard and soft tissues in three dimensions, providing greater information with a potential decrease in cumulative radiation exposure for patients (Jaykishan, 2019). The latest diagnostic methods and more sophisticated research apparatuses have brought about a scientific revolution. In the present study, we aimed to set up a protocol for evaluation of OITRR in bicuspids using micro-computed tomography.

2. Materials and methods

2.1. Sample collection

Extracted teeth were collected from teenage patients going through orthodontic treatment at the University of Alberta. The study was accepted by the at the King Abdul Aziz University (KAAU) Health Research Ethics Board (protocol # Pro00001454). Ten maxillary first premolars were collected; five teeth which acted as control were extracted before the commencement of orthodontic treatment, and the remaining five teeth that were to be studied were extracted from patients who had orthodontic treatment for 1 year on average. Extraction was done due to a change in the original treatment plan to extraction in order to resolve the discrepancy in space, disproportionate incisor proclination, midline discrepancy. and/or to increase the lip competency. The subjects were healthy in general except for their occlusion. The mean age of the subjects was 14 years 4 months (+/-1 year 9 months) (3 males, 2 females) in the control group, compared to 15 years 5 months (+/- 1 year 7 months) (3 females) in the study group. All subjects had malocclusion Class I with an average of 4–6 mm crowding. Orthodontic treatment which all the subjects went through involved dental arches expansion, by applying progressive series of nitinol archwires like 0.014, 0.016, 0.018 round and 0.016 × 0.022 rectangular cross-section in the McLaughlin Bennett Trevisi preadjusted bracket system with a slot size of 0.022 (3 M Unitek, Monrovia, CA, USA). Premolars were extracted and stored in 70% ethanol for decontamination. The decrees to extract the premolars were made at the beginning of the treatment. All patients had CBCT before treatment as part of their initial orthodontic diagnostic records. Initial root length of all teeth was made from CBCT using Dolphin imaging software version 11.8, USA.

2.2. Scanning of teeth by micro-CT

Extracted teeth were dried by air for half an hour and axially scanned in a Skyscan 1076 Micro-CT imager using the vendor-provided imaging control software (Version 2.6.0; Skyscan N.V., Kontich, Belgium). The projections of the image were acquired at a tenacity of 9 μm with help of an x-ray source potential of 100 kVp, 100μA, and power of 10 Watt. To upsurge the mean photon energy of the source of x-ray beam, a 1.0-mm thickness filter made of aluminum was utilized; the average per step was 3 scan projections, through the 180° rotation at 0.5° step increment. The recreation of the raw image data was preformed using NRecon software Version 1.4.4 (SKYSCAN, Kartulzersweg 3B 2990 Kentich, Belgium) using a modified Feldkamp back projection method. Teeth were carefully chosen using a 0.0 to 0.06 picture to cross-section software threshold according to the area of interest.

2.3. Analysis of root resorption

Scanned teeth of recreated pictures were studied utilizing CT analyzer (Version 1.6.1.0, Skyscan N.V., Kontich, Belgium). To study the resorption lacunae the following was made, sampling each 50th slice over the root length of the tooth, beginning with the 226 slices, which corresponds to the biological width dimension average of 2.04 mm^2, under the Cemento Enamel Junction (CEJ) and continuing to the root tip. (Gargiulo et al., 1961) The location of the lacunae, length and breadth of the lacunae, Number of lacunae and the of tooth root resorbed percentage were all among the measured indices.

To compute the proportion of root resorbed, as determined by analysis software, the volume of the tooth was assessed based on the volume of the tooth root, and adding to it the size of all resorption lacunae found. Reconstructed 3-D interpretations of teeth analyzed were observed employing computed tomography (CT) volume Realistic 3D-Visualization (Version 1.10.0.5, Skyscan NV).

2.4. Blinding

The root resorption evaluation was performed by one blinded author who has no information about the patients' treatment techniques. Data were labelled and coded to be sent to a statistician who was also blinded regarding patients' groups

2.5. Study error

The eighteen randomly selected patients' measurements, 6 from each group, were remeasured after an interval of 4-weeks then compared to calculate the measurement errors. The Dahlberg formula ($S_e^2 = \sum d^2/2n$) was used to calculate the accuracy of measurements, where Se2 is the error variance, d is the difference between repeated measurements and n is the number of paired repeated measurements. (Eissa et al., 2018)

3. Results

3.1. Distribution of lacunae resorption on the root surface

A considerably large number of resorption lacunae were seen on the teeth root surfaces that were undergoing orthodontic treatment when compared to control teeth. The most noticeable observation was that the teeth in the control group had resorption bays situated on the palatal, mesial, and distal surfaces only, while the teeth from the treatment group had resorption lacunae on all surfaces. Applying the Mann-Whitney test, remarkable dissimilarities were found among the control group and the study treatment group on all root surfaces. (P = 0.008, 0.015, 0.005, and 0.007 on mesial, distal, buccal, and palatal surfaces, respectively).

Among the teeth in the orthodontic treatment group, there was an obvious dissimilarity in the resorption lacunae number midst of different surfaces (P = 0.020). On the mesial surface there was an ominously large number of resorption lacunae of the teeth compared to the palatal and buccal aspects. Thus, marked differences were observed in the number of resorption lacunae depending upon their presence on various root surfaces of the teeth among the control group and teeth in orthodontic treatment group. (P = 0.009, the typical values are 25 and 1, respectively).

3.2. Resorption lacunae length and width

Samples in the orthodontic control group and treatment group exhibited inconsistency in the coronoapical length and width of the resorption bay, utilizing more inconsistency comprehended in the control samples. The length and breadth of the lacunae in the orthodontic treatment group were significantly greater than those observed in the samples from the control group (P = 0.009 and 0.047 for depth and height, respectively).

3.3. Resorption lacunae area

The teeth from the control group and teeth in orthodontic treatment group displayed a resorption lacunae average area < 1 mm^2, with larger variation in the area of lacunae in the teeth in orthodontic treatment group. The teeth in the orthodontic treatment group had a remarkably greater area of resorption bays compared to the control samples.

3.4. Proportion of root area that endured resorption

To decide the degree of resorption, the clinical area of tooth root was assessed by the summation of the total area of resorption bay in a tooth to the calculated clinical tooth root area from the cementoenamel junction. Teeth in the control group and teeth in orthodontic treatment group showed low proportions of resorption in comparison to the entire tooth area; nevertheless, teeth in orthodontic treatment group had on an average of a 52-times more resorption of the entire tooth configuration compared to the teeth in the control group after 1st year of orthodontic treatment (P = 0.009).

The process of demineralization underlying resorption bays was seen in many root resorption lacunae. The demineralized dentin existed as lacunar regions underneath the resorption lacunae and measured to be at a lesser Hounsfield unit threshold (i.e., a lower CT density/attenuation value), which was visualized as light color on the grey-scale compared to the dark mineralized soft bone matrix. It was also observed that areas of demineralized softened dentin were existent in the teeth in the orthodontic treatment group only ranging from 0.12 to 275 m^2 compared to the resorption lacunae size. The size of demineralization was directly proportional to resorption lacunae size. Teeth in the control group had no subjacent zones of dentin demineralization. Instead, they exhibited a basal level of tooth resorption.

4. Discussion

Earlier studies conducted about root resorption mostly were concerning the resorption caused by controlled orthodontically induced tooth movement. (Jimenez-Pellegrin and Arana-Chavez, 2004; Han et al., 2005) In the present study, the group under investigation consisted of teeth that were collected from patients enduring the orthodontic treatment for 1 year prior to extraction. This study compared initial root length changes as measured from initial CBCT to actual root length as measured by Micro CT after 1 year of orthodontic treatment. The outcomes of this study are in agreement with previous studies that showed that teeth that did not exposed to orthodontic forces had less resorption lacunae compared to teeth that underwent orthodontic treatment. The finding that the proximal surfaces of teeth in orthodontic treatment group had comparatively more resorption lacunae compared to other surfaces was true for our study too. (Harris et al., 2006) This finding was explained by the fact that maximum root surface area is on the mesial and distal aspect and thus more resorption is obvious on these surfaces.

The previous studies published on root resorption explained root resorption in terms of volumes of resorption lacunae, (Chan and Darendeliler, 2005; Harris et al., 2006) but in this study, we studied the area of resorption and also the size of resorption lacunae concerning length and breadth. In the present study, it was seen that area of resorption lacunae was larger in the teeth in the orthodontic treatment group compared to the teeth from the control group. This finding was consistent with the published results. (Chan and Darendeliler, 2005; Harris et al., 2006)

The present study is the first to compute the amount of teeth resorption in teeth that underwent orthodontic treatment for 1 year as compared to their initial root length as measured from CBCT. Root resorption is usually estimated by scrutinizing orthopantomographs or intraoral periapical radiographs. Nevertheless, minor alterations in root resorption cannot be precisely calculated by these approaches. (AlKhalifa and AlAzemi, 2014; Wierzbicki et al., 2009)

In the present study micro-CT was used after extraction of these premolars in order to explain at higher resolution the possible changes in root length as compared to initial lengths. The average amount of resorption was calculated to be 0.9% of the tooth root volume in teeth that have been orthodontically treated for 1 year (Wierzbicki et al., 2009).

The most important observation of the present research was the spotting of crucial regions of demineralized dentin underlying numerous root resorption lacunae. These regions characterize a zone of ongoing root resorption, with odontoclastic/cementoclastic resorption leading to acid production in that zone and additional dentin demineralization. Moreover, these areas epitomize the complete magnitude of impending root loss (Brudvik and Rygh, 1995). The early resorption lacunae are small and have the potential for repair if the tooth movement is discontinued. Sustained pressure will result in continual resorption leading to significant and clinically appreciable root resorption (Brudvik and Rygh, 1994; Jaykishan, 2019). Since demineralized regions are not constantly related to each resorption lacunae, the absenteeism of underlying demineralization will indicate that the resorption lacuna has become dormant (Wierzbicki et al., 2009). Thus, the invention and utilization of a high-resolution imaging technology must be done so that it is proficient in measuring the demineralized foci in vivo and in situ and future.

A limitation of this study is the small sample size as few cases fulfilled our study criteria. Another limitation of this study is the difference in scanning resolution between the initial CBCT and micro–CT. Future studies may be planned to evaluate high resolution initial and final CBCTs of teeth after orthodontic treatment.

5. Conclusions

This study presents a unique method of evaluating orthodontics induced tooth root resorption after one year of dental arch expansion by comparing initial root length from CBCT to after extraction lengths from Micro CT. The restricted field of view, high resolution, low-dose CBCT might be used in the future to monitor and /or assess in vivo OITRR clinically.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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