


CONE BEAM COMPUTED TOMOGRAPHY FOR THE DIAGNOSIS OF EXTERNAL ROOT RESORPTION ASSOCIATED WITH ORTHODONTIC TREATMENT: A REVIEW

TOMOGRAFÍA COMPUTARIZADA DE HAZ CÓNICO PARA EL DIAGNÓSTICO DE LA REABSORCIÓN RADICULAR EXTERNA ASOCIADA AL TRATAMIENTO DE ORTODONCIA. UNA REVISIÓN

Mariela Burgos-Urey¹ 
dra.mburgos@gmail.com

Jhoana Mercedes Llaguno-Rubio² 
academico@ilaeperu.com

ABSTRACT

External root resorption (ERR) is a highly prevalent, multifactorial problem frequently associated with orthodontic treatment. Treatment is complex due to the lack of solid knowledge regarding predisposing factors, systematic management for diagnosis and follow-up protocols or the fundamental theoretical bases of adequate imaging tools for each situation.

This review describes the indications of the use of cone beam computed tomography (CBCT) and the factors related to its development and the characteristics of the techniques used in the diagnosis and monitoring of ERR in orthodontics. We compared the advantages and disadvantages of CBCT based on the risk/benefits. **Methods:** We have reviewed and summarized the information and the risk factors available on ERR in orthodontics and the use of CBCT in the diagnosis and follow-up of ERR with the aim of developing a management protocol. Likewise, CBCT is compared with other imaging techniques frequently used in ERR. The articles reviewed in this study coincide in terms of the advantages of precision of CBCT in the detection and linear and volumetric measurement of ERR associated with orthodontics over two-dimensional techniques. However, CBCT cannot completely replace other imaging techniques since its effectiveness is not significantly greater in cases with moderate ERR compromise. The use of CBCT should be optimized following specific criteria for its application.

Keywords: External root resorption, orthodontics, Cone beam computed tomography.

Artículo recibido: 10/09/2020
Arbitrado por pares
Artículo aceptado: 13/11/2020
Autor publicado: 10/12/2020

Corresponding Author:
Mariela Burgos-Urey
dra.mburgos@gmail.com

RESUMEN

La reabsorción radicular externa (RRE) es un problema frecuentemente asociado con el tratamiento de ortodoncia, de alta prevalencia, multifactorial y de considerable complejidad cuando se carece de conocimiento sólido respecto de los factores predisponentes, el manejo sistemático para el diagnóstico y el protocolo de seguimiento, además de bases teóricas fundamentales en cuanto a herramientas imagenológicas adecuadas para cada situación.

El presente estudio tiene como objetivo describir las indicaciones para el uso de la tomografía computarizada de haz cónico (TCHC) para el diagnóstico y el seguimiento de la RRE asociada a ortodoncia, considerando factores informados en la literatura que intervienen en su desarrollo y en las características de las técnicas imagenológicas utilizadas, comparando sus ventajas y desventajas fundamentadas en el valor de riesgo/beneficio. La información descrita sobre RRE asociada a ortodoncia, factores de riesgo y uso de TCHC para el diagnóstico y seguimiento sugerido en la literatura se revisó y resumió para ser orientada hacia un protocolo de manejo. Asimismo, se realizaron comparaciones con otras técnicas imagenológicas frecuentemente utilizadas con el mismo propósito. Los artículos revisados en este estudio concuerdan en cuanto a las ventajas de precisión en la detección y en la medición lineal y volumétrica de la RRE asociada a ortodoncia, respecto de las técnicas bidimensionales; sin embargo, está claro que no las reemplaza por completo,

Cite as: Burgos-Urey M, Llaguno-Rubio J. Cone beam computed tomography for the diagnosis of external root resorption associated with orthodontic treatment: A review. *Rev Cient Odontol (Lima)*. 2020; 8 (3): e037.
DOI: 10.21142/2523-2754-0803-2020-037

¹ Division of Orthodontic, Universidad Mayor de San Simón. Cochabamba, Bolivia.

² Division of Oral and Maxillofacial Radiology, Universidad Científica del Sur. Lima, Peru.

ya que las diferencias en términos de modificación del plan de tratamiento como consecuencia del hallazgo resultan ser poco significativas en situaciones de compromiso moderado. El uso de la TCHC debe optimizarse siguiendo criterios específicos para su aplicación.

Palabras clave: reabsorción radicular externa, ortodoncia, tomografía computarizada de haz cónico

INTRODUCTION

External root resorption (ERR) is one of the main side effects that occurs during or after orthodontic treatment (1). It is caused by sterile inflammation, induced by the load of tooth movement that can lead to resorption of superficial root cement (2), which is usually clinically insignificant. However, more than one third of the original length of the root may be lost in more severe cases (3), leading to eventual resorption of the underlying dentin, compromising the longevity of the tooth (4).

The prevalence of ERR is high and the factors involved are multiple and complex (5). These factors may be internal, inherent to the patient, or external, related to local factors, mainly orthodontic treatment. Currently, 2-dimensional (2D) radiographic evaluation is the main method of detection and localization of ERR (6). However, panoramic radiography has shown to either over- or underestimate root shortening by up to 20% compared to, for example, periapical radiography (1). Since root resorption is a process that occurs in three-dimensional (3D) structures, 2D images cannot detect resorption on the lingual or buccal surface or quantify the volume of root loss (5). Additionally, there is the superposition of anatomical structures as well as angulation of the X-ray beam. Four anatomical structures are affected during orthodontic treatment: bone, periodontal ligament, pulp and root cement (7), all of which are, to some extent, involved in ERR.

Early-stage ERR with a small diameter and depth may go unnoticed in a 2D X-ray and, can worsen and affect prognosis if not diagnosed and controlled (6). On the other hand, cone beam computed tomography (CBCT) can be very useful since it allows 3D evaluation of the structures, facilitating the localization and determination

of the extension of ERR, with multiplanar cuts favoring accurate diagnosis (8) and the identification of teeth at risk of developing severe resorption in early stages (9). However, the higher cost and radiation exposure often make this modality inappropriate as the first option. Nonetheless, advances in imaging technology, have led to CBCT becoming the non-invasive technique of choice for diagnosis, providing complete and precise information in high resolution (8).

It is important to recognize the risk factors that predispose the patient to developing ERR, in order to determine the need for a thorough examination using CBCT. The objective of this study was to carry out a review of the literature on the risk factors of ERR and the relevance of performing individualized complementary examinations using CBCT, according to the needs of each patient.

MATERIALS AND METHODS

A bibliographic review was carried out on the use of CBCT for the diagnosis of ERR associated with orthodontics in the main databases of the international scientific literature on health sciences (MEDLINE) until December 2019. The databases of PubMed and SCIELO were reviewed using the descriptors: “external root resorption”, “cone beam computed tomography”, “orthodontic treatment” and their Spanish counterparts. As a result of the search, 112 articles were obtained and screened in order to select the most relevant studies based on the elements of the review. Thus, this review was limited to 47 articles that included original articles, literature review articles, systematic reviews and meta-analyses. Opinion articles and letters to the editor were excluded.

Predisposing factors of external root resorption (ERR) during and after orthodontic treatment and their imagenological correlation

The etiology of ERR is multifactorial involving inflammatory resorption⁽¹⁰⁾ due to a very complex combination of biological variability, genetic predisposition and mechanical factors⁽¹¹⁾. According to the literature, approximately 80% of patients undergoing orthodontic treatment can develop a certain degree of ERR⁽¹²⁾.

The internal factors related to ERR include genetic aspects, age of treatment initiation, root formation and development, root morphology, type of malocclusion, and others that are generally easily discernible in initial radiographic studies for orthodontic treatment⁽¹³⁾. External factors are related to aspects of the treatment, such as the type of appliance, the technique, the application, magnitude and direction of force, premolar extraction, increased overjet, closure of spaces in one or two stages, duration of treatment and use of elastics^(13, 14). Another important factor described in recent studies is the approximation, especially post-treatment, of the root to the cortical plates⁽¹⁵⁾. Consequently, considering all the aforementioned and the fact that inflammation is essential in tooth movement and is a fundamental component of the root resorption process, knowledge of these particularities, mechanical control and imaging monitoring during and after orthodontic treatment are essential to get a well-done clinical practice.

Therefore, radiological evaluation of ERR should include root morphology and length, endodontic treatment, bone morphology, agenesis, ectopy, invaginations and proximity to the cortices, among other aspects⁽¹⁶⁾. Regarding root morphology, the rhomboidal, triangular, dilacerated and pipette-shaped forms can be distinguished with rhomboid-shaped forms having a lower risk of ERR⁽¹⁷⁾ while dilacerated roots present the greatest risk⁽¹³⁾ according to the literature. Regarding root length, several studies have shown that teeth with short roots are more susceptible to developing ERR and have a poorer prognosis⁽¹⁸⁾.

Regarding the most affected dental group, it has been shown that teeth in the anterior region (incisors and canines) present significantly higher amounts of ERR than those in the posterior region (premolars and molars)⁽¹⁹⁾. Consequently, in the presence of a greatly increased overjet, requiring a proportionally greater amount of correction, large displacement of the anterior sector is involved, and by being the most vulnerable, a greater risk of root resorption can be expected.

The type of malocclusion is no less important as it is directly related to the therapeutic measures to be taken. For example, deep bite requiring correction through anterior intrusion mechanics is a risk factor that must be adequately monitored, since intrusive movement is often associated with the risk of developing root resorption due to compression of the root apex and periodontium^(20,21). In the same way, studies on treatment with extractions report significantly higher amounts of ERR compared to treatments without extractions, which could be explained by being directly related to the greater amount of dental displacement and a potentially longer duration of treatment, with an average increase in ERR of 0.36 mm for each additional year⁽¹⁹⁾.

Canine impaction can increase the risk of ERR⁽²²⁾ since, in general, correction lasts approximately 6 months longer than conventional treatment, with this time tending to increase when impaction is bilateral⁽²³⁾ and even more so when the canines are bicortically impacted and located close to the midline, constituting a greater risk of root resorption of the maxillary incisors due to direct contact⁽²⁴⁾.

The proximity of the root apex to the buccal, lingual corticals and the incisor canal is also associated with ERR^(25,26). For this reason, they have been described as "orthodontic walls", and represent an anatomical limit for movement and root positioning during treatment. This zone is considered dangerous due to the increased risk of iatrogenic reabsorption⁽²⁷⁾. Orthodontic treatment plans must carefully consider all the aspects described above.

2D and 3d imagenological studies in the diagnosis of external radicular resorption (ERR)

ERR is part of the process of removing the hyalinization zone ⁽²⁸⁾. Depending on the affected tissues, ERR is classified into 3 categories: resorption of cement with remodeling, resorption of dentin with repair, and circumferential root resorption ⁽²⁹⁾. In the first category, only the outer layer of cement is resorbed and subsequently remodeled, which is not very observable by 2D radiographs. In the second category, the cement and the outer layer of dentin are resorbed and subsequently repaired with cement. At this stage radiographic changes can be observed in the apical region. In the third category there is an evident loss of root tissue and a radiographically quantifiable shortening in which the shape of the root may or not be the same as the original ⁽²⁹⁾.

Levander and Malmgren proposed a useful diagnostic classification for the various types of ERR with respect to the degree of severity ⁽³⁰⁾. In this classification, five levels are distinguished, ranging from Grade 0 to Grade 5, where 0 indicates absence of resorption, 1 represents mild resorption with irregular contour and normal root length, 2 indicates moderate resorption in which small areas of loss of root tissue are observed and the apex has an almost straight line outline; 3 indicates severe resorption, with loss of almost a third of the original root length; and 4 indicates extreme resorption with loss of more than a third of the initial root length ⁽³¹⁾. This classification can be applied in evaluation by both 2D radiographs and CBCT, the latter being more precise to quantify slight degrees of change and to locate the loss of tissue on the root surfaces in the three spatial planes ⁽³²⁾.

Data obtained traditionally using 2D images show magnification, deformation and positioning problems ⁽⁵⁾. Previous studies reported that periapical radiographs underestimate root length by an average of 2.6 mm compared to less than 0.3 mm for CBCT ⁽³³⁾. Similarly, panoramic radiographs can show distortion when the teeth are outside the focal corridor, which is usually the case with anterior teeth in patients with severe Class II or Class III malocclusions ⁽¹⁵⁾.

The value of CBCT for the diagnosis and monitoring of ERR lies in its ability to obtain reproducible images of roots without distortion ⁽¹⁾. In addition, 3D reconstruction of multiplanar sections of CBCT allows the exploration, precise quantification and linear and volumetric measurements related to ERR ⁽³⁴⁾. Thus, CBCT also compensates for changes in root position and angulation during and after orthodontic treatment ⁽³⁵⁾.

CBCT studies have shown that 94% of patients present at least 1 root with more than 1 mm of ERR, possibly not diagnosed by other techniques, and that 6.6% of patients present at least 1 root with a resorption greater than 4 mm ⁽²²⁾.

Many authors agree that the presence of resorption craters is determined by the region of the root surface where the compression load is concentrated and, to a lesser extent, stress, which, in turn, derives from the direction of the force applied. Consequently, it has been reported that with respect to the location of the ERR, the apical vestibular surfaces are high pressure areas resulting in greater susceptibility to resorption in response to twisting movements. It is therefore important to emphasize the advantages of a 3D diagnosis since the affected areas are very often buccal and lingual root surfaces that can be seen in CBCT but not in 2D radiographs ⁽³⁶⁾.

The quality of the images obtained by CBCT depends on parameters such as milliamperes (mA), kilovoltage (Kv), and voxel size. The effect of small voxel size has been demonstrated in many studies in the literature ⁽³⁷⁾. In terms of reliability and precision as functions of voxel size, studies conducted with a voxel size ≤ 0.20 mm reported a significantly higher ERR compared to those with a larger voxel size. Similarly, other data indicate that the measurement error of tooth and root length with CBCT is smaller with a voxel size of 0.20 mm compared to periapical intraoral radiography and CBCT with larger voxel sizes ⁽³⁸⁾. One comparative study concluded that the measurement capacity with CBCT was 100% compared to 95% in periapical radiography, with panoramic radiography showing a highly variable lower percentage for estimating the root length of maxillary incisors ⁽³⁹⁾.

Another study evaluated 275 teeth using orthopantomography (OPT) and CBCT based on the Levander and Malmgren classification. The result showed that 145 teeth presented “Grade 0” by OPT, that is, no resorption, while only 80 teeth showed this absence of resorption by CBCT. In this group, mild resorption was observed in 92 teeth by OPT and in 128 teeth by CBCT, and 21 teeth showed moderate resorption by OPT compared to 48 teeth by CBCT with this classification⁽¹⁾, demonstrating a significant underestimation of ERR by OPT. Likewise, intraoral and extraoral 2D radiographs are subject to manipulation of brightness, contrast, sharpness and other aspects which could show false signs of mild RRE or mask certain changes in early stages⁽⁴⁰⁾.

Some additional advantages of CBCT lie in the field of research of ERR associated with orthodontic treatment, since it can be used *in vivo* and with less radiation exposure compared to conventional computed tomography⁽⁵⁾.

Protocol for imagenological control of ERR

The amount of ERR during and after orthodontic treatment is associated with the duration and other aspects of the treatment already mentioned, basically due to the persistent bone turnover associated with prolonged tooth movement⁽⁴¹⁾. Six months after treatment, it is suggested to obtain periapical radiographs of the most vulnerable teeth involved in the treatment to observe changes in the shape of the root that can project global information. These teeth usually involve the incisors since they are considered to be at greater risk of ERR. When resorption is detected in periapical radiography, it is recommended to stop the movement for two to three months with passive arches to allow cellular cement healing^(2,30).

In the absence of radiographic signs of irregularities in the root contour at six to nine months after starting orthodontic treatment, it is unlikely for later resorption to occur or it would not be significant, indicating whether or not strict posterior imaging follow-up is necessary⁽²⁾. When radiographic signs of ERR are present, 2D

imaging techniques have important limitations, mainly related to the lack of reproducibility and various degrees of distortion that make monitoring difficult^(1,42).

Regarding diagnosis by CBCT, it has been proposed that the study be carried out in 2 stages: the first at the beginning of treatment and the second near the end of treatment (approximately 9 months) in patients with factors predisposing ERR. In these patients, a third long-term tomographic follow-up study should be considered 3 to 5 years after the end of the treatment, always using the “as low as reasonably achievable” (ALARA) principle^(36,43). In this regard, it is essential to take into account the considerable variation in the radiation doses of CBCT according to the exposure protocol with a difference of up to 15 times greater between a high and a low resolution protocol with the same field of view⁽⁴⁴⁾.

Only a proportion of patients may benefit from a change in the treatment plan as a consequence of ERR, and therefore, the evidence-based indications for the use of CBCT for diagnosis are currently limited to particular cases⁽¹⁹⁾. Consequently, the decision as to whether to use high-resolution, radiation-dose CBCT protocols to diagnose a clinically irrelevant amount of ERR should be based on sound assessment of the risk/benefit ratio for the patient^(6,19,45).

The prognosis of ERR is generally favorable. It has even been stated that ERR is less critical in apical periodontal support than in the loss of alveolar support secondary to periodontal disease associated with orthodontic treatment, since it has been observed that 3 mm of apical root loss is equivalent to 1 mm of loss alveolar ridge bone⁽⁴⁶⁾. This is due to the fact that the area of periodontal union of the conical root perimeter surrounding the root substantially decreases from the cervical third towards the apical region⁽²⁾, and that although a loss of root length of up to 50% is detrimental to tooth stability, most authors do not recommend extraction and prosthetic replacement of the same⁽⁴⁷⁾. Even after severe ERR (greater than 4 mm or 1/3 of the root length) in which the loss of periodontal attachment is considerable, the teeth would continue to function acceptably for several years.

DISCUSSION

Compared to other imaging techniques, CBCT provides multiple advantages for the diagnosis of ERR in terms of precision in linear measurement and the possibility of volumetric quantification of root loss for correct diagnosis and information for clinical management. The present review describes the criteria for the application of CBCT in the diagnosis and follow-up of ERR associated with orthodontics.

ERR associated with orthodontic treatment is a high incidence, multifactorial induced inflammatory resorption conditioned by the presence of different internal and external factors that predispose patients to develop this condition. The literature highlights that certain internal elements such as root morphology, type of malocclusion, age of initiation of treatment and external elements such as duration, therapeutic mechanics, the need for intrusive movement, large dental displacements and impacted teeth, among others are involved in the development of ERR.

The diagnostic classification used to quantify root resorption is that of Levander and Malmgren in which five levels are distinguished. In these five levels grade 0 indicates the absence of resorption, 1 represents mild resorption (irregular contour and normal root length), 2 indicates moderate resorption (small areas of loss of root tissue and the apex with an almost straight line contour); 3 indicates severe resorption (loss of up to one third of the original root length); and 4 indicates extreme resorption (loss of more than one third of the root).

With the use of CBCT images can be obtained without distortion for the diagnosis of ERR. Unlike the 2D techniques that frequently present problems of magnification, deformation, projection of structures and positioning, CBCT images are reproducible for follow-up. However, only a proportion of patients can benefit from this alternative since, despite its advantages, these are usually not significant enough to justify its application in terms of risk/benefits based on the ALARA principle.

According to several authors, follow-up protocols should include CBCT studies at the beginning of orthodontic

treatment, 6 to 9 months later, and at the end and at 3 to 5 years after treatment in cases identified as high risk of presenting ERR. Likewise, the literature highlights the importance of not generalizing this protocol to all patients, but rather it should be used on an individual basis.

CONCLUSIONS

CBCT has proven to be an excellent technique for the diagnosis of ERR which is frequently associated with orthodontic treatment, due to the possibility of performing 3D studies for the detection of ERR even in early stages. While CBCT provides multiple advantages for the diagnosis of ERR in terms of precision in linear measurement and the possibility of volumetric quantification of root loss, it cannot be applied in all patients. Therefore, the decision to use high-resolution, radiation-dose CBCT protocols to diagnose a clinically irrelevant amount of ERR should be based on the risk/benefit ratio for the patient.

It is essential to consider the relative advantages of CBCT over conventional radiographs taking into account the quality of the information provided, the potential impact on diagnosis, treatment planning as well as the higher cost of this technique and its utility versus the risk induced by radiation exposure.

Authors contribution: Mariela Burgos-Urey and Jhoana Mercedes Llaguno-Rubio have participated in the preparation of the article, the collection of the information, the writing and approval of the final version.

Funding Source: Self-financed.

Potential conflicts of interest: The authors declare that they have no conflict of interest.

REFERENCES

1. Dudic A, Giannopoulou C, Leuzinger M, Kiliaridis S. Detection of apical root resorption after orthodontic treatment by using panoramic radiography and cone-beam computed tomography of super-high resolution. *Am J Orthod Dentofacial Orthop.* 2009; 135 (4): 434-7. doi: 10.1016/j.ajodo.2008.10.014
2. Feller L, Khammissa RA, Thomadakis G, Fourie J, Lemmer J. Apical external root resorption and repair in orthodontic tooth movement: biological events. *Biomed Res Int.* 2016; 2016: 4864195. doi: 10.1155/2016/4864195
3. Castro I, Valladares-Neto J, Estrela C. Contribution of cone beam computed tomography to the detection of apical root resorption after orthodontic treatment in root-filled and vital teeth. *Angle Orthod.* 2015; 85 (5): 771-6. doi: 10.2319/042814-308.1
4. Castro IO, Alencar AH, Valladares-Neto J, Estrela C. Apical root resorption due to orthodontic treatment detected by cone beam computed tomography. *Angle Orthod.* 2013; 83 (2): 196-203. doi: 10.2319/032112-240.1
5. Deng Y, Sun Y, Xu T. Evaluation of root resorption after comprehensive orthodontic treatment using cone beam computed tomography (CBCT): a meta-analysis. *BMC Oral Health.* 2018; 18 (1): 116. doi: 10.1186/s12903-018-0579-2
6. Goller BD, Ugur AZ. The impact of different voxels and exposure parameters of CBCT for the assessment of external root resorptions: A phantom study. *Aust Endod J.* 2019; 45 (2): 146-53. doi: 10.1111/aej.12354
7. Ruskyte G, Juozenaite D, Kubiliute K. Types of root resorptions related to orthodontic treatment. *Stomatologija.* 2019; 21 (1): 22-7.
8. Deliga AG, Westphalen FH, Schroder JC, Fernandes A, Westphalen VPD. Accuracy of digital periapical radiography and cone-beam computed tomography for diagnosis of natural and simulated external root resorption. *J Endod.* 2018; 44 (7): 1151-8. doi: 10.1016/j.joen.2018.03.011
9. Poleti ML, Fernandes TM, Paiz CC, Rubira-Bullen IR, Capelozza AL. Pixel value analysis for detection of simulated early external root resorption. *Braz Oral Res.* 2014; 28. doi: 10.1590/1807-3107bor-2014.vol28.0045
10. Vlaskalic V, Boyd RL, Baumrind S. Etiology and sequelae of root resorption. *Semin Orthod.* 1998; 4 (2): 124-31. doi: 10.1016/s1073-8746(98)80009-1
11. 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 (4): 462-76; discussion 12A. doi: 10.1016/j.ajodo.2009.06.021
12. Motokawa M, Sasamoto T, Kaku M, Kawata T, Matsuda Y, Terao A, et al. Association between root resorption incident to orthodontic treatment and treatment factors. *Eur J Orthod.* 2012; 34 (3): 350-6. doi: 10.1093/ejo/cjr018
13. Fernandes LQP, Figueiredo NC, Montalvany Antonucci CC, Lages EMB, Andrade I Jr., Capelli Junior J. Predisposing factors for external apical root resorption associated with orthodontic treatment. *Korean J Orthod.* 2019; 49 (5): 310-8. doi: 10.4041/kjod.2019.49.5.310
14. Lee YJ, Lee TY. External root resorption during orthodontic treatment in root-filled teeth and contralateral teeth with vital pulp: A clinical study of contributing factors. *Am J Orthod Dentofacial Orthop.* 2016; 149 (1): 84-91. doi: 10.1016/j.ajodo.2015.06.027
15. Aman C, Azevedo B, Bednar E, Chandiramami S, German D, Nicholson E, et al. Apical root resorption during orthodontic treatment with clear aligners: A retrospective study using cone-beam computed tomography. *Am J Orthod Dentofacial Orthop.* 2018; 153 (6): 842-51. doi: 10.1016/j.ajodo.2017.10.026
16. Brezniak N, Wasserstein A. Orthodontically induced inflammatory root resorption. Part II: The clinical aspects. *Angle Orthod.* 2002; 72 (2): 180-4. doi: 10.1043/0003-3219(2002)072<0180:OIIRRP>2.0.CO;2
17. Patel S, Mavridou AM, Lambrechts P, Saberi N. External cervical resorption-part 1: histopathology, distribution and presentation. *Int Endod J.* 2018; 51 (11): 1205-23. doi: 10.1111/iej.12942
18. Cutrera A, Allareddy V, Azami N, Nanda R, Uribe F. Is Short Root Anomaly (SRA) a risk factor for increased external apical root resorption in orthodontic patients? A retrospective case control study using cone beam computerized tomography. *Orthod Craniofac Res.* 2019; 22 (1): 32-7. doi: 10.1111/ocr.12254
19. Samandara A, Papageorgiou SN, Ioannidou-Marathiotou I, Kavvadia-Tsatala S, Papadopoulos MA. Evaluation of orthodontically induced external root resorption following orthodontic treatment using cone beam computed tomography (CBCT): a systematic review and meta-analysis. *Eur J Orthod.* 2019; 41 (1): 67-79. doi: 10.1093/ejo/cjy027
20. Harris DA, Jones AS, Darendeliler MA. Physical properties of root cementum: part 8. Volumetric analysis of root resorption craters after application of controlled intrusive light and heavy orthodontic forces: a microcomputed tomography scan study. *Am J Orthod Dentofacial Orthop.* 2006; 130 (5): 639-47. doi: 10.1016/j.ajodo.2005.01.029
21. Puttaravutti P, Wongsuwanlert M, Charoemratrote C, Leethanakul C. Volumetric evaluation of root resorption on the upper incisors using cone beam computed tomography after 1 year of orthodontic treatment in adult patients with marginal bone loss. *Angle Orthod.* 2018; 88 (6): 710-8. doi: 10.2319/121717-868.1
22. 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 (3): 480-7. doi: 10.2319/061311-390.1
23. Arriola LE, Ruíz GA, Rodríguez YA, Aliaga A, Dias HL. Root resorption of maxillary incisors after traction of unilateral vs bilateral impacted canines with reinforced anchorage. *Am J Orthod Dentofacial Orthop.* 2018; 154 (5): 645-56. doi: 10.1016/j.ajodo.2018.01.015
24. Arriola LE, Rodríguez YA, Ruíz GA, Aliaga A, Schilling J, Dias HL. Three-dimensional evaluation of the root resorption of maxillary incisors after the orthodontic traction of bicortically impacted canines: case reports. *Prog Orthod.* 2019; 20 (1): 13. doi: 10.1186/s40510-019-0267-z

25. Nakada T, Motoyoshi M, Horinuki E, Shimizu N. Cone-beam computed tomography evaluation of the association of cortical plate proximity and apical root resorption after orthodontic treatment. *J Oral Sci.* 2016; 58 (2): 231-6. doi: 10.2334/josnurd.15-0566
26. Pan Y, Chen S. Contact of the incisive canal and upper central incisors causing root resorption after retraction with orthodontic mini-implants: A CBCT study. *Angle Orthod.* 2019; 89 (2): 200-5. doi: 10.2319/042318-311.1
27. Handelman CS. The anterior alveolus: its importance in limiting orthodontic treatment and its influence on the occurrence of iatrogenic sequelae. *Angle Orthod.* 1996; 66 (2): 95-109; discussion -10. doi: 10.1043/0003-3219(1996)066<0095:TAAIII>2.3.CO;2
28. Brudvik P, Rygh P. The repair of orthodontic root resorption: an ultrastructural study. *Eur J Orthod.* 1995; 17 (3): 189-98. doi: 10.1093/ejo/17.3.189
29. Brezniak N, Wasserstein A. Orthodontically induced inflammatory root resorption. Part I: The basic science aspects. *Angle Orthod.* 2002; 72 (2): 175-9. doi: 10.1043/0003-3219(2002)072<0175:OIIRRP>2.0.CO;2
30. Levander E, Malmgren O, Eliasson S. Evaluation of root resorption in relation to two orthodontic treatment regimes. A clinical experimental study. *Eur J Orthod.* 1994; 16 (3): 223-8. doi: 10.1093/ejo/16.3.223
31. Levander E, Malmgren O. Evaluation of the risk of root resorption during orthodontic treatment: a study of upper incisors. *Eur J Orthod.* 1988; 10 (1): 30-8. doi: 10.1093/ejo/10.1.30
32. Zasciurinskiene E, Lund H, Lindsten R, Jansson H, Bjerklin K. Outcome of orthodontic treatment in subjects with periodontal disease. Part III: a CBCT study of external apical root resorption. *Eur J Orthod.* 2019; 41 (6): 575-82. doi: 10.1093/ejo/cjz040
33. Sherrard JF, Rossouw PE, 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 (4 Suppl): S100-8. doi: 10.1016/j.ajodo.2009.03.040
34. Akyalcin S, Alexander SP, Silva RM, English JD. Evaluation of three-dimensional root surface changes and resorption following rapid maxillary expansion: a cone beam computed tomography investigation. *Orthod Craniofac Res.* 2015; 18 Suppl 1: 117-26. doi: 10.1016/j.ajodo.2009.03.040
35. Holberg C, Steinhäuser S, Geis P, Rudzki-Janson I. Cone-beam computed tomography in orthodontics: benefits and limitations. *J Orofac Orthop.* 2005; 66 (6): 434-44. doi: 10.1007/s00056-005-0519-z
36. 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 (3): 181-90. doi: 10.1007/s00056-018-0133-5
37. Bagis N, Eren H, Kolsuz ME, Kurt MH, Avsever H, Orhan K. Comparison of the burr and chemically induced periodontal defects using different field-of-view sizes and voxel resolutions. *Oral Surg Oral Med Oral Pathol Oral Radiol.* 2018; 125 (3): 260-7. doi: 10.1016/j.oooo.2017.11.010
38. Lund H, Gröndahl K, Gröndahl HG. Cone beam computed tomography for assessment of root length and marginal bone level during orthodontic treatment. *Angle Orthod.* 2010; 80 (3): 466-73. doi: 10.2319/072909-427.1
39. Al-Okshi A, Paulsson L, Rohlin M, Ebrahim E, Lindh C. Measurability and reliability of assessments of root length and marginal bone level in cone beam CT and intraoral radiography: a study of adolescents. *Dentomaxillofac Radiol.* 2019; 48 (5): 20180368. doi: 10.1259/dmfr.20180368
40. Nascimento EHL, Gaeta-Araujo H, Galvao NS, Moreira-Souza L, Oliveira-Santos C, Freitas DQ. Effect of brightness and contrast variation for detectability of root resorption lesions in digital intraoral radiographs. *Clin Oral Investig.* 2019; 23 (8): 3379-86. doi: 10.1007/s00784-018-2764-8
41. Eissa O, Carlyle T, El-Bialy T. Evaluation of root length following treatment with clear aligners and two different fixed orthodontic appliances. A pilot study. *J Orthod Sci.* 2018; 7: 11. doi: 10.4103/jos.JOS_120_17
42. Roscoe MG, Meira JB, Cattaneo PM. Association of orthodontic force system and root resorption: A systematic review. *Am J Orthod Dentofacial Orthop.* 2015; 147 (5): 610-26. doi: 10.1016/j.ajodo.2014.12.026
43. De Freitas JC, Lyra OC, De Alencar AH, Estrela C. Long-term evaluation of apical root resorption after orthodontic treatment using periapical radiography and cone beam computed tomography. *Dental Press J Orthod.* 2013; 18 (4): 104-12. doi: 10.1590/s2176-94512013000400015
44. Ludlow JB, Timothy R, Walker C, Hunter R, Benavides E, Samuelson DB, et al. Effective dose of dental CBCT-a meta analysis of published data and additional data for nine CBCT units. *Dentomaxillofac Radiol.* 2015; 44 (1): 20140197. doi: 10.1259/dmfr.20140197
45. Sonmez G, Koc C, Kamburoglu K. Accuracy of linear and volumetric measurements of artificial ERR cavities by using CBCT images obtained at 4 different voxel sizes and measured by using 4 different software: an ex vivo research. *Dentomaxillofac Radiol.* 2018; 47 (8): 20170325. doi: 10.1259/dmfr.20170325
46. Ericson S, Kurol J. Incisor root resorptions due to ectopic maxillary canines imaged by computerized tomography: a comparative study in extracted teeth. *Angle Orthod.* 2000; 70 (4): 276-83. doi: 10.1043/0003-3219(2000)070<0276:IRRDTE>2.0.CO;2
47. Lee KS, Straja SR, Tuncay OC. Perceived long-term prognosis of teeth with orthodontically resorbed roots. *Orthod Craniofac Res.* 2003; 6 (3): 177-91. doi: 10.1034/j.1600-0544.2003.02276.x