Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 11, Issue, 06, pp. 47697-47701, June, 2021
https://doi.org/10.37118/ijdr.21868.06.2021

ISSN: 2230-9926

RESEARCH ARTICLE

OPEN ACCESS

CROSS-SECTIONAL ANALYSIS OF DETECTION OF EXTERNAL ROOT RESORPTIONS SIMULATED BY DIGITAL SUBTRACTION RADIOGRAPHY: IN VITRO STUDY

Tony V. Faria[1], Juliana C. Carmelo[1], Claudia S. Valerio[1], Gabriel C. Nascimento[2], Micheline S. Khour, G. Rodrigues[1], Isabela C. Ribeiro[1], Elton G. Zenóbio, Amaro I. Vespasiano[1] and Flávio R. Manzi[1]

[1]Department of Dentistry/Oral Radiology , School of Dentistry, Pontifical Catholic University of Minas Gerais, Belo Horizonte, Brazil; [2]Department of Dentistry, School of Dentistry, Pontifical Catholic University of Minas Gerais, Belo Horizonte, Brazil

ARTICLE INFO

Article History:

Received 18th March, 2021
Received in revised form
26th April, 2021
Accepted 08th May, 2021
Published online 26th June, 2021

Key Words:

Dental digital radiography, Subtraction techniques, Root resorptions, Oral diagnosis.

Corresponding author: Tony V. Faria,

ABSTRACT

Early detection of external root resorption (ERR) is important for the adoption of an appropriate treatment plan in order to avoid greater damage in root structures. The present study aimed to evaluate the efficacy of digital subtraction radiography (DSR) for detecting root resorptions in maxillary central incisors. The ERRs were simulated and analyzed through digital radiographs and DSR methods.This study selected 36 maxillary central incisors with healthy roots. The teeth had their original root length reduced by 0.5 mm, 1.0 mm, 1.5 mm, and 2.0 mm in the apical-coronal direction. Then, the teethwere regularly and irregularly worn with dental bur on the buccal surface, 4 mm cervical to the tooth's apex, featuring two groups (n = 20 and n= 16, respectively). The digital radiographs were obtained using a photostimulable storage phosphor (PSP) imaging plate, and the images were subtracted by the linear and logarithmic methods. Ten dentists tested the diagnostic capacity of digital radiography and of digital subtraction radiography in detecting the ERRs. The DSR, both linear and logarithm, had a better performance when compared to the evaluation conducted only with digital radiography in apical and buccal ERRs of 0.5 mm and 1.0 mm ($P< 0.05$).The digital subtraction radiography method, both linear and logarithm,wasmore effective in the identification of small external root resorptions than digital radiography and can aid dental professionals in the early detection of ERRs.

Citation: Tony V. Faria, Juliana C. Carmelo, Claudia S. Valerio, Gabriel C. Nascimento, Lizandra G. Rodrigues, Isabela C. Ribeiro, Amaro I. Vespasiano and Flávio R. Manzi1, 2021. "Cross-sectional analysis of detection of external root resorptions simulated by digital subtraction radiography: in vitro study", *International Journal of Development Research*, 11, (06), 47697-47701.

INTRODUCTION

External root resorption (ERR) is the loss of cementum and dentine as a result of odontoclastic cell action, caused by inflammation (Patel, 2009 and Deliga Schröder, 2018). This can occur as a consequence of many stimulation factors, including trauma, apical infection, internal bleaching, periodontal treatment, ectopic eruption, and when in the presence of orthodontic movement (Deliga Schröder, 2018 and Fuss, 2003). Many studies have observed worrisome incidence and prevalence rates of apical root resorption in orthodontically treated patients (Newman, 1975; Levander, 1998 and Ono *et al*., 2011). For Smale *et al*., nearly 15.5% of the patients have one or more incisors with root resorption of at least 2 mm in length from 3 to 9 months after beginning fixed appliance therapy (Smale, 2005). Another study found an 8% prevalence rate of root resorptions of greater than 3 mm in length after 12 months of treatment (Årtun, 2005). During and even, in some cases, suspending it, so that the progression of ERR can be avoided (Levander *et al*., 1998 and Chapnick, 1989). Root resorption is generally asymptomatic, and one of the only ways of diagnosing and measuring its severity is through radiographic imagery; however, a reliable diagnosis can only be performed five to six months after the beginning of orthodontic treatment. The periapical radiograph is the most common diagnostic method used to detect the presence of external apical root resorptionsbut, in many cases, with low precision (Brezniak, 2004; Westphalen, 2004). Digital subtraction radiography (DSR) is a technique that allows two radiographs in the same anatomic region, at different times, to have their respective coinciding structures removed, resulting in an image that represents only the difference between the two images (Ono, 2011). The technique allows one to view the changes between the two images, which would normally be impossible by the naked eye (Takeshita, 2013). There are many methods that can make two radiographs become geometrically identical, and the success of the technique depends on this (Takeshita, 2013). Two methods of image acquisition were classified as *priori* and *posteriori*. The *priori* methodincludes those taken before the acquisition of the image, with positioners for the patient's head and images of the bite. The *posteriori* method refers to those acquired after the images have been obtained, which are used as digital resources by different types of software to generate geometric standardization or imageequalization (Samarabandu, 1994). Considering the high prevalence of root resorptions caused by orthodontic treatment, coupled with the difficulty of early diagnosis, this study sought to evaluate and compare the detectability of digital radiography and DSR in diagnosis of ERRs located on the root's apex and on the buccal surface of the root of maxillary incisors.

MATERIAL AND METHODS

Sample: The experimental group consisted initially of44 permanent maxillary central incisors. These teeth presented healthy roots, with normal morphology, with no root dilacerations and/or curvatures. The crowns of the incisors that presented cavities due to dental caries were restored with 3M Filtek® Z250 photopolymerizable resin (3M do BrasilLtda, Sumaré, Brazil), thus reestablishing the dental anatomy and providing radiopacity in the reconstructed regions. In the first phase of the study the 44 teeth were prepared in order to simulate the external apical root resorption. At the time of the simulation of external apical root resorption, eight teeth were lost due to perforation of the pulp chamber. Among these eight teeth, two teeth would be prepared to simulate ERRs on the buccal surface of the root (regular cavities), and six would be prepared to simulate ERRs on the buccal surface of the root (irregular cavities). Thus, the final experimental group consisted of 36 permanent maxillary central. In the second phase, the teeth were subdivided into two groups in order to simulate ERRs on the buccal surface of the root: 20 teeth were prepared to simulated regular ERRs cavities e 16 teeth were prepared to simulated irregular ERRs cavities. The study design is outlined by the flowchart (Figure 1).

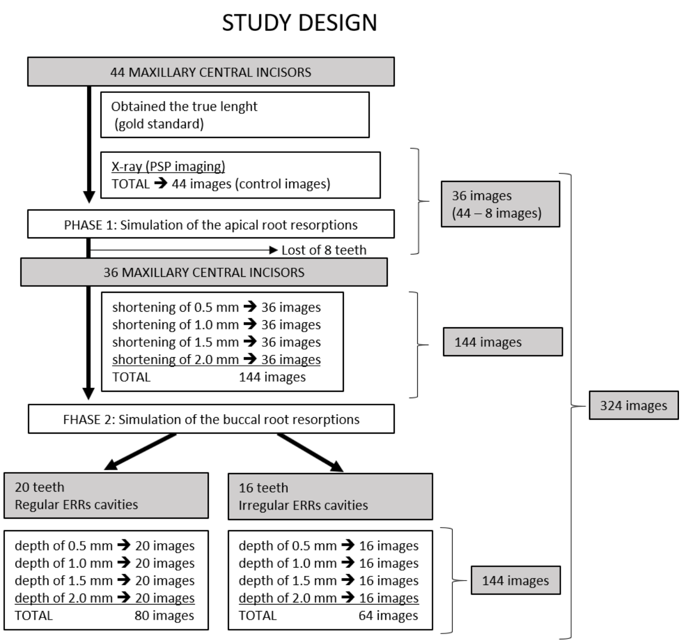

Figure 1. Flowchart

Image acquisition: The true length of the maxillary central incisors was obtained by two evaluators by means of a digital pachymeter (Canadá Inc., Mitutoyo, Canada). The measurements of true length were repeated twice by both examiners, and the final average of the measurements represented the true length of the teeth (gold standard). Next, each maxillary incisor was X-rayed, using a photostimulable storage phosphor (PSP) imaging plate (DenOptix QST, Gendex, Hatfield, USA). These radiographs were taken by a single operator, using the dental X-ray unit GE 1000 (General Electric Company, Milwaukee, Wisconsin, USA), operating at 65 kV, 10 mA, with an aluminum filter of 1.5 mm in thickness (de Almeida, 2003). The exposure time was of 0.20 s. The acquired images were exported and stored in TIFF format, operating at a resolution of 300 dpi, with a pixel size of 0.085 X 0.085 mm, matrix of 485 x 367pixels with 8 bits to quantify the gray levels and the special resolution of 6lp/mm. In an attempt to simulate the conditions of the oral cavity, while taking the digital radiographs, the incisors were positioned in the alveolus of a sectioned maxilla from a dry skull, forming a bone/tooth block. The alveolus of the sectioned maxilla was filled with a dense condensation silicon, Silon 2 APS Denso® (Detsply® Indústria e ComercioLtda, Petrópolis, Brazil), and the incisor was introduced into the alveolus, positioning its long axis parallel to the lower edge of the bone block. Consequently, the incisor remained in a parallel position, both in relation to the lower edge of the acrylic box as well as in relation to the digital sensor (Figure 2). The sectioned maxilla containing the incisors, that is, the bone/tooth block, was then positioned below an acrylic box of 2 cm in height, containing water, to attenuate the X-ray beams, simulating the soft tissues.[15] For the acquisition of these images, the radiographic technique of parallelism was applied in a standardized manner with the aid of a cylindrical acrylic box without a top to allow for the introduction of the X-ray tubes from the radiographic device. This provided the standardization of the focus-film and the focus-sensor distance at 40 cm and allowed for a perpendicular incidence of the X-ray beams (Figure 2).

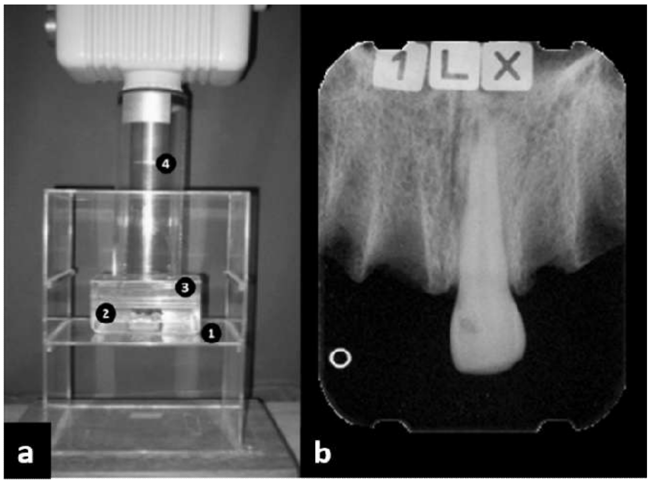

Figure 2. (a) Acrylic device for the standardization of the parallelism technique and (b) radiography obtained with the standardization of the technique. (1) Lower edge of the acrylic box, (2) bone/tooth block, (3) acrylic recipient containing water, (4) acrylic cylinder containing the X-ray tube

Simulation of the apical root resorptions: The ERRs were simulated on the root apex of the 36 teeth, using a number 3145 diamond bur (KG Sorensen Indústria e ComércioLtda, Barueri, Brazil) which gradually reduced the total length of the tooth by 0.5 mm, 1.0 mm, 1.5 mm, and 2.0 mm. With each root reduction, the incisors were measured with the pachymeter and X-rayed with the PSP.

Simulation of buccal root resorptions: The 36 teeth used in the first step were subdivided into two groups: the first with 20 teeth and the second with 16 teeth. In both groups, wear was performed in order to simulate ERRs on the buccal surface of the root, on the apical third, and 4 mm cervical to the tooth's apex, using a number 4 spherical diamond bur (KG Sorensen Indústria e ComércioLtda, Barueri, Brazil). In the first group, the root resorption presented regular edges, according to the cylindrical diamond bur format used in the wear process. By contrast, in the second group, the margins of root resorption simulated in this study proved to be irregular. The creation of this format sought to obtain a root lesion similar to real ERRs. After each of the resorptions had been created, they were then measured using a probe that measures in millimeters (Trinity Indústria e ComércioLtda, Jaraguá, Brazil). The lesions presented a depth of 0.5 mm. This dimension was later increased sequentially to 1.0 mm, 1.5 mm, and 2 mm.

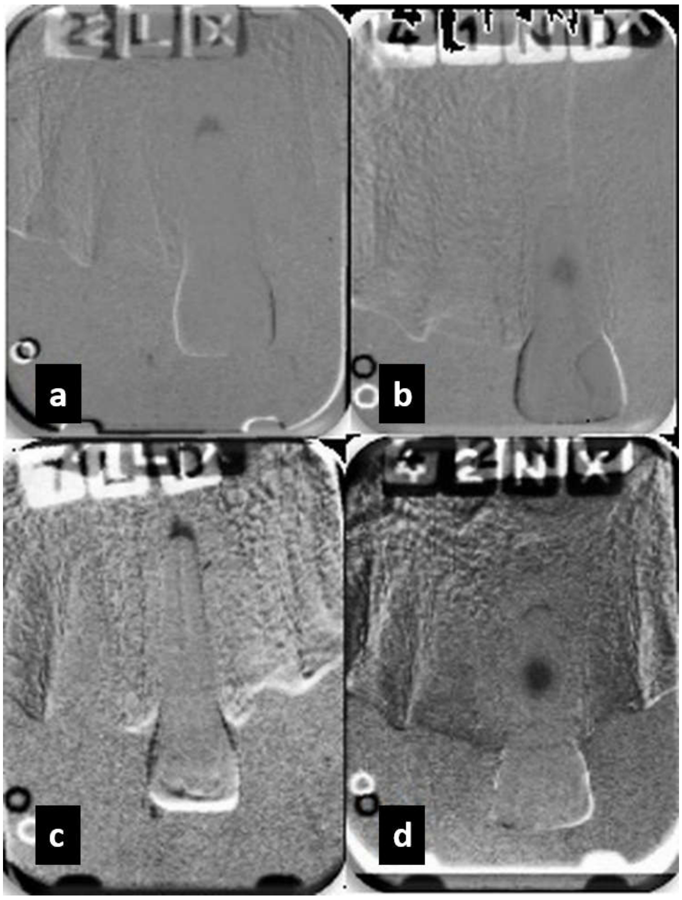

Figure 3. Digital linear subtraction radiography with apical (a) and vestibular (b) resorption. Digital logarithmic subtraction radiography with apical (c) and vestibular (d) resorption

Linear and logarithmic digital subtraction: In total, 324 digital radiographs were obtained. The image count is in the flowchart (Figure1). All of the radiographs received codes that informed to which tooth each one belonged, the type of resorption, and the degree of resorption. Next, the radiographs were submitted to the process of digital subtraction by means of the Emago® Advanced v3.2. software (Oral Diagnostic Systems, Amsterdam, The Netherlands). So that the results of the subtractions would be more precise, the commands of Y corrections from Emago®, which calibrates the gray levels of the radiographs, and the reconstruction command, which carries out the geometric fine-tuning between two paired radiographs, were used. This fine-tuning was carried out by selecting four identifiable points between the two radiographs, which, once selected, paired the images through an algorithm, making them geometrically coincident. All of these parameters of alignment and correction of gray levels added to the care when taking the radiographs, and were sufficient to make both images paired and spatially aligned so that the linear subtraction could be performed properly (Figure 2). The method of logarithmic or non-linear digital subtraction was also applied, allowing for the definition of the minor differences between the two radiographs through the increase in the structural noise and the contrast. To reduce the structural noise, the command of 'defined filter' was used (Figure 3) (Bittar-Cortez, 2006). This study obtained images subtracted between the healthy tooth and each of the types of simulated resorption of 0.5 mm, 1.0 mm, 1.5 mm, and 2.0 mm, resulting in a total of 288 images of linear subtraction and 288 images logarithmic subtraction.

Evaluation of images: The X-ray images were evaluated by ten dentists, all experts in imagery, trained to examine the images with digital radiography, as well as with linear and logarithmic subtraction radiography. The images were classified according to the following diagnostic options: clearly presented root resorption (a), probably presents root resorption (b), there is no way to affirm (c), probably does not present root resorption (d), and clearly does no present root resorption (e). The images were randomly codified and made available so that the examiners could assess the images blindly and independently.

Statistical test: After having obtained the data from the examiners, this information was tabulated and compared to the real measurements (gold standard). The statistical test was applied for the non-parametric ordinal data through the Friedman test, at a 5% significance level, using the BioEstat 5.0 software (Instituto de Desenvolvimento SustentávelMamirauá, Belém, Pará, Brazil).

RESULTS

Apical Resorptions: The use of DSR, both linear and logarithm, had a better performance when compared to the evaluation conducted only with digital radiography in the resorptions of 0.5 mm and 1.0 mm, as well as a similar and efficient performance at resorption levels of 1.5 mm and 2.0 mm ($P< 0.05$)

Irregular buccal resorptions: The use of linear and logarithmic DSRs presented a better performance when compared to the results obtained with digital radiography at resorption levels of 0.5 mm and 1.0 mm, as well as efficient and similar results in the three diagnostic methods at resorption levels of 1.5 mm and 2.0 mm ($P< 0.05$)

Regular buccal resorptions: The best results occurred when the linear and logarithmic DSRs were used to compare diagnoses with digital radiography at resorption levels of 0.5 mm and 1.0 mm. Similar results were also found among all of the methods evaluated in the diagnosis of resorptions of 1.5 mm and 2.0mm ($P< 0.05$)

DISCUSSION

Orthodontically treated patients are subject to ERR. The early diagnosis of ERR allows for the modification of orthodontic planning, or even it suspension, in an attempt to prevent the progression of ERR and possible tooth loss. CBCT imaging is the most accurate method to detect ERRs, (Deliga Schröder, 2018) however, it is a diagnostic method with a higher dose of radiation and a higher cost. In the present study, two different DSR methods were tested by two groups of professionals in order to test the accuracy of these methods. In the DSR method, alterations in the mineral quantity are projected upon a neutral gray background, and for this reason the sensitivity in the diagnosis is greater than that in conventional radiographs (Christgau, 1998; Tyndall, 1990). This method has a 90% detection rate of resorptions as small as those that affect up to 5% of the root (Yi, 2006). In the present study, when evaluating the performance of DSR methods, the superiority of both types of subtraction were observed, especially in the identification of apical resorptions of 0.5 mm to 1.5 mm, as well as regular and irregular buccal resorptions of 0.5 mm and 1.0 mm. One prerequisite for DSR to be properly used is that the two radiographs to be subtracted must be spatially similar, with minimal variation (Ono, 2011 and Kullendorff, 1988). The standardization methods for the images to be subtracted before and after having been obtained, called *"priori"* and *"posteriori"*,[13] are not excluded and, in fact, complement each other. Mol *et al.*[21] simulated angulation errors in radiographs to evaluate the capacity of Emago® to correct these errors and concluded that there is a high correspondence among the corrected radiographic images, of up to 6º of angulation, with images correctly angled, which makes it essential to establish a minimal *priori* standardization of any image to be subtracted. It is important to stress that the corrections carried out *posteriori* were small in proportion, hence ensuring a good correlation among the analyzed images. As regards the diagnostic method, when comparing DSR, both logarithmic and linear, with digital radiography, the superiority of DSR was observed in both techniques when diagnosing simulated radiographic resorptions of a lesser proportion. A similarity was also found between DSR and digital radiography in resorptions of lesser proportion. The comparisons in the literature between DSR and the digital radiography, for the most part, are quantitative evaluations, using the measurement tools from either the subtraction program or the histogram to evaluate the density of the pixelsand, therefore, of the resorption. Using the histogram from the Emago® program, Bittar-Cortez *et al*.[16] quantitatively evaluated the value of the pixels in a peri-implant region in digital radiography as well as in linear and logarithmic DSR. The authors concluded that the monitoring of bone density in this region, to evaluate the value of the gray scale, can be performed by both DSR methods or by digital radiography, since they present similar results. In a study conducted for quantitative and qualitative evaluations, the roots of maxillary canines were measured before and after retraction in orthodontic treatment. Radiographs were taken, and these were subtracted so that the density of the gray level could be evaluated. A parity was observed in the inefficiency to detect apical resorptions in both methods (Perona, 1996). However, when the diagnostic capacity of the conventional radiographs was compared with DSR in simulated ERRs, the superiority of DSR was observed. It has been suggested that one of the factors for better subtraction results is to reduce the structural noise, allowing for the detection of details that, in other circumstances, would be lost (Kravitz, 1992). In the end, this is possibly the greatest advantage of subtraction: upon eliminating the presence of other anatomic images around any variation between the radiographs, the difference is highlighted.

In the present study, this was most likely the fact that made the results of DSR, both linear and logarithmic, better than those found for conventional radiographs. For quantitative detection, through DSR or the digital radiography of simulated root resorptions of small proportions in incisors, Heo *et al*. (Heo, 2001) demonstrated the superiority of DSR in the diagnosis. Nonetheless, such images were generated with diamond burs that made the edges of the lesions more vivid. Moreover, subtraction in the buccal resorptions was not evaluated. When comparing digital radiography with DSR, in simulated root resorptions, it was observed that the method became significantly better only for the detection of lingual resorptions of up to 1 mm, with no difference for larger lesions nor for apical lesions. Resorptions of less than 0.5 mm were not detected by any of the methods, corroborating with the results found in the present study (Ono, 2011). In recent studies, which used the DSR method to diagnosis the vertical root fractures, interproximal caries and bone loss around metal implants, better results were obtained when compared with digital radiography images (Takeshita, 2013; Queiroz, 2016; Kapralos, 2020; Geraets, 2011). The results after bone and membrane graft, in patients with periodontal bone defects, is also better seen using the radiographic subtraction method (Górski, 2019). In addition to the external root resorption shown in this study, the diagnosis of internal root resorptionwith DSR had more accuracy when compared with conventional radiographic images (Holmes, 2001). In the present study, two groups had their root resorptions simulated on the buccal surface, one with vivid edges made by diamond burs and the other with more diffuse edges, similar to that observed *in vivo*. The results, however, point out an equality in the detection of both types of lesions. The radiographic subtraction method has strong clinical applicability because it is a low-cost and low-radiation method, with results proven in the literature in several areas, as previously described (Kapralos, 2020). The DSR method is significantly better for the detection of ERRs, however, one of the limitations with diagnosing of external cervical root resorption is that intraoral radiographs only reveal limited diagnostic information (Patel, 2009). Besides that, additional clinical randomized controlled trials are necessary for detecting and monitoring the progress of external root resorption.

CONCLUSIONS

The results of the present study showed that DSR, both logarithmic and linear, increased the detectability of simulated external root resorptions cavities. It improved diagnostic accuracy of digital radiography in detecting ERRs of small dimensions. So, elucidating the importance of DSR as a tool in the early diagnosis of ERRs.

Financial support and sponsorship: None.

Conflicts of interest: There are no conflicts of interest.

Acknowledgements: This project was supported by the Foundation of Research Support for the State of Minas Gerais (Fundação de Amparo a Pesquisa do Estado de Minas Gerais - FAPEMIG), and CAPES Foundation.

REFERENCES

Patel S, Dawood A, Wilson R, Horner K, Mannocci F. The detection and management of root resorption lesions using intraoral radiography and cone beam computed tomography - an in vivo investigation. Int Endod J. 2009;42:831–838.

Deliga Schröder ÂG, Westphalen FH, Schröder JC, Fernandes Â, Westphalen VPD. Accuracy of Digital Periapical Radiography and Cone-beam Computed Tomography for Diagnosis of Natural and Simulated External Root Resorption. J Endod. 2018;44:1151–1158.

Fuss Z, Tsesis I, Lin S. Root resorption--diagnosis, classification and treatment choices based on stimulation factors. Dent Traumatol. 2003;19:175–182.

Newman WG. Possible etiologic factors in external root resorption. Am J Orthod. 1975;67:522–539.

Levander E, Bajka R, Malmgren O. Early radiographic diagnosis of apical root resorption during orthodontic treatment: A study of maxillary incisors. Eur J Orthod. 1998;20:57–63.

Ono E, Medici Filho E, Faig Leite H, Tanaka JLO, De Moraes MEL, De Melo Castilho JC. Evaluation of simulated external root resorptions with digital radiography and digital subtraction radiography. Am J Orthod Dentofac Orthop. 2011;139:324–333.

Smale I, Årtun J, 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. Am J Orthod. 2005;128:57–67.

Årtun 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;75:919–926.

Chapnick L, Endo D. External root resorption: An experimental radiographic evaluation. Oral Surgery, Oral Med Oral Pathol. 1989;67:578–582.

Brezniak N, Goren S, Zoizner R, Dinbar A, Arad A, Wasserstein A, *et al*. A comparison of three methods to accurately measure root length. Angle Orthod. 2004;74:786–791.

Westphalen VPD, De Moraes IG, Westphalen FH, Martins WD, Souza PHC. Conventional and digital radiographic methods in the detection of simulated external root resorptions: a comparative study. Dentomaxillofac Radiol. 2004;33:233–235.

Takeshita W, Iwaki LV, Da Silva M, Filho L, Queiroz AF, Geron LG. Comparison of the diagnostic accuracy of direct digital radiography system, filtered images, and subtraction radiography. Contemp Clin Dent. 2013;4:338-342.

Samarabandu J, Allen KM, Hausmann E, Acharya R. Algorithm for the automated alignment of radiographs for image subtraction. Oral Surg Oral Med Oral Pathol. 1994;77:75–79.

de Almeida SM, de Oliveira AEF, Ferreira RI, Bóscolo FN. Image quality in digital radiographic systems. Braz Dent J. 2003;14:136–141.

Borg E, Källqvist A, Gröndahl K, Gröndahl HG. Film and digital radiography for detection of simulated root resorption cavities. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998;86:110–114.

Bittar-Cortez JA, Passeri LA, Bóscolo FN, Haiter-Neto F. Comparison of hard tissue density changes around implants assessed in digitized conventional radiographs and subtraction images. Clin Oral Implants Res. 2006;17:560–564.

Christgau M, Hiller KA, Schmalz G, Kolbeck C, Wenzel A. Quantitative digital subtraction radiography for the determination of small changes in bone thickness: An in vitro study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998;85:462–472.

Tyndall DA, Kapa SF, Bagnell CP. Digital subtraction radiography for detecting cortical and cancellous bone changes in the periapical region. J Endod. 1990;16:173–178.

Yi WJ, Heo MS, Lee SS, Choi SC, Huh KH. ROI-based image registration for digital subtraction radiography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2006;101:523–529.

Kullendorff B, Gröndahl K, Rohlin M, Henrikson CO. Subtraction radiography for the diagnosis of periapical bone lesions. Dent Traumatol. 1988;4:253–9.

Mol A, Dunn SM. The performance of projective standardization for digital subtraction radiography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2003;96:373–382.

Perona G, Wenzel A. Radiographic evaluation of the effect of orthodontic retraction on the root of the maxillary canine. Dentomaxillofac Radiol. 1996;25:179–185.

Kravitz LH, Tyndall DA, Bagnell CP, Dove SB. Assessment of external root resorption using digital subtraction radiography. J Endod. 1992;18:275–284.

Heo MS, Lee SS, Lee KH, Choi HM, Choi SC, Park TW. Quantitative analysis of apical root resorption by means of digital subtraction radiography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2001;91:369–373.

Queiroz PM, Nascimento HAR, da Paz TDJ, Anacleto FN, Freitas DQ. Accuracy of Digital Subtraction Radiography in the Detection of Vertical Root Fractures. J Endod. 2016;42:896–899.

Kapralos V, Koutroulis A, Irinakis E, Kouros P, Lyroudia K, Pitas I, Mikrogeorgis G. Digital subtraction radiography in detection of vertical root fractures: accuracy evaluation for root canal filling, fracture orientation and width variables. An ex-vivo study.Clin Oral Investig. 2020.

Geraets WGM, Verheij HGC, WismeijerD, van der Stelt PF.Detecting bone loss along dental implants by subtraction of panoramic radiographs. Clinical Oral Implants Research.2011; 23(7): 861–865.

Górski B, Jalowski S, Górska R, Zaremba M. Treatment of intrabony defects with modified perforated membranes in aggressive periodontitis: subtraction radiography outcomes, prognostic variables, and patient morbidity. Clin Oral Investig 2019;23(7):3005–3020.

Holmes JP, Gulabivala K, van der Stelt PF. Detection of simulated internal tooth resorption using conventional radiography and subtraction imaging. DentomaxillofacRadiol2001; 30(5): 249-254.

Patel S, Dawood A, Wilson R, Horner K, Mannocci F. The detection and management of root resorption lesions using intraoral radiography and cone beam computed tomography - an in vivo investigation. IntEndod J. 2009;42(9):831–838.

****