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Abstract

Aim External apical root resorption (EARR) is a common complication that may occur during and after orthodontic treatment. In case of need of endodontic therapy for a tooth with EARR, it has not been clarified yet which benefits can be derived by the use of electronic apex locators (EALs). The present study aimed to assess the accuracy of EALs on extracted teeth before and after simulation of EARR subsequent to orthodontic treatment.

Materials and methods Standard access cavities were prepared on 64 single-rooted teeth. After working length (CWL) determination, specimens were embedded in an alginate mass, connected to two EALs (Apit, Osada, Tokyo, Japan; Root ZX, Morita Corp., Tokyo, Japan) and the electronic working length (EWL) was measured. The apical portion of the specimens was then modified to simulate EARR, and the EWL was determined again. The discrepancy between CWL and EWL was regarded as statistical unit. Collected data underwent statistical analysis by means of non-parametric tests (p < 0.05).

Results Within a range of ±0.5 and ±1.0 mm from CWL, the accuracies were 79.7% and 98.4% (Apit/intact tooth); 82.8% and 96.9% (Apit/simulated EARR); 81.3% and 98.4% (Root ZX/intact tooth); 76.6% and 96.9% (Root ZX/simulated EARR). No statistically significant differences in relation to device or apical condition emerged (p > 0.05).

Conclusion The two considered EALs showed similar accuracy, which was not affected by the EARR simulation. The use of EALs in the treatment of teeth with EARR following orthodontic treatment may be useful.

Keywords Electronic apex locator; Orthodontics; Root resorption; Working length.

Introduction

External apical root resorption (EARR) is a common complication that may occur following orthodontic treatment, especially in case of heavy intrusive or tipping forces [Hamilton and Gutmann, 1999]; its severe form, presenting a 4 mm or one-third loss of the root length, has an incidence of 1 to 5% in orthodontically treated teeth [Lupi et al., 1996]. A recent study performed by using cone-beam computed tomography found that some degree of resorption take place in all orthodontically treated teeth [Leite et al., 2012]. Clinically relevant EARR occurs mainly in the anterior segment of both jaws, but maxillary teeth are the most severely affected ones [Sameshima and Sinclair, 2001].

Post-orthodontic EARR starts as an ischemic necrosis of the periodontal ligament when the orthodontic force is applied [Pizzo et al., 2007; Topkara, 2011; Llamas-Carreras et al., 2012]. A wide array of studies has been produced in order to understand the aetiology and predictive factors implicated in the EARR process, but this issue has not been clarified yet [Llamas-Carreras et al., 2012]. The relevance of several risk factors has been questioned both in relation to the orthodontic treatment (duration of treatment, the direction and magnitude of the force) and to the patient characteristics (genetic predisposition, systemic diseases, anomalies in root anatomy, orofacial trauma, previous endodontic treatment) [Pizzo et al., 2007]. Interestingly, it has been stated that similar post-orthodontic EARR occur in endodontically treated and untreated maxillary incisors [Esteves et al., 2007].

EARR is generally regarded as surface resorption or transient inflammatory resorption [Hamilton and Gutmann, 1999], so that pathological modifications are likely to occur in the apical third of the root, while the rest of the canal has a good chance of remaining anatomically unaltered. In some cases, EARR may determine the loss of pulp vitality and therefore the need of root canal treatment [Filho et al., 2006]. There are further circumstances that may require the endodontic treatment of a tooth with a resorbed apex,
in vitro measurements of apical resorption

e.g. subsequent caries, traumatic injuries or prosthetic rehabilitations. The treatment strategies of teeth with open apex involves the use of calcium hydroxide, and more recently mineral trioxide aggregate [Cehreli et al., 2011]; however, there is lack of high-level evidence on the proper treatment for EARR and clinicians should plan the means of managing each case with regard to their clinical experience and to patient-related factors [Ahangari et al., 2010]. In such cases technical difficulties to proper root canal shaping and filling may be present, working length (WL) determination in the first place.

Root canal instrumentation and filling should ideally terminate at the cemento-dentinal junction [Ricucci and Langeland, 1998], but this anatomical landmark can be lost as a result of EARR. Traditionally, the WL has been determined by means of periapical radiography and became more accurate and predictable with the advent of electronic apex locators (EALs) [Gordon and Chandler, 2004]. However, according to some authors [Herrera et al., 2007], the assessment of working length in canals with open apices is less predictable than in roots with a small-sized apical foramen. Although alternative techniques for working length determination have been recently suggested [ElAyouti et al., 2009], the treatment of teeth with open or resorbed apex remains a challenge for the clinician.

Clinical studies on accuracy of EALs in patients with resorbed teeth as a consequence of orthodontic treatment are difficult to achieve because it is hard to enrol a sufficient number of patients with severe EARR [Sameshima and Sinclair, 2001]. To the best of our knowledge, no previous laboratory study measured the WLs on the same specimens before and after the simulation of EARR.

The aim of this in vitro study was to determine whether the simulation of EARR influences the accuracy of electronic apex locators.

Materials and methods

Specimen selection

Sixty-four undecayed single-rooted permanent teeth were extracted for periodontal reasons. Teeth with root curvatures greater than 10 degrees were excluded from the experimentation. Periodontal ligament remnants and calculus deposits were removed using manual curettes; the teeth were then disinfected by immersion in 5.25% NaOCl (Niclor 5, Ogna, Milan, Italy) for 5 minutes and stored into saline solution at 37°C. Standard access cavity was prepared using a round bur mounted on high speed handpiece under water irrigation and a Batt bur on a low speed handpiece.

Reference standard method

Actual root canal length was established by inserting a size 10 K-file (Dentsply-Maillefer, Ballaigues, Switzerland) into the root canal until its tip reached the plane of the major foramen and the proper positioning was verified using a stereomicroscope (Wild Makroskop M420; Heerbrugg, Switzerland) at a magnification of x15, as described by Pascon et al. [2009]. The silicone stop was positioned upon the most coronal area of the tooth and the length was measured to the nearest 0.5 mm; the control working length (CWL) was established 0.5 mm short of this value, according to anatomical findings [Dummer et al., 1984].

Electronic working length determination

Alginate (Plus Phase fast setting, Zhermack Clinical, Marl, Germany) was mixed with tap water according to the indications of the manufacturer and poured into plastic boxes; specimens and EAL labial electrodes were therein embedded before the alginate setting, as shown in figure 1. Canals were irrigated with a 5.25% NaOCl solution.

Electronic working length (EWL) was measured using Apit (Osada, Tokyo, Japan) and Root ZX (Morita Corp., Tokyo, Japan). Temperature was kept constant at 21±1°C. EWL was registered with the two devices connected to a size 10 K-File, which was inserted into the canal. Every device was set according to the indications of the manufacturer. The measurement method described by Dunlap et al. [1998] was adopted: the file was slowly led beyond the apex mark on the locator’s screen and then withdrawn until the apex mark was displayed again; in this position, the silicon stop was adjusted on the coronal reference point and EWL was acquired.

Simulation of root resorption

Each tooth was shortened by removing the apical 4 mm of the root with a cutting disc. The apical 3 mm of the canal were enlarged backwards with No. 1, 2 and

![FIG. 1 Schematic representation of the alginate-based model for electronic length determination. a) specimen; b) endodontic file; c) alginate mass; d) labial electrode; e) apex locator.](image-url)
3 Gates Glidden burs (Mani, Tochigi, Japan) and the dentin walls were ground with a diamond cylindrical bur to obtain 0.5 mm-thick walls at the apex. The CWL and the EWL were determined again as described above; before embedding the modified specimens in alginate, a small amount of soft wax was plugged into the apical foramina to prevent the alginate to enter the canal backwards while still in sol state. After alginate setting the teeth were gently extracted from the alginate mass in order to remove the wax, and then reinserted.

Statistical analysis

Before the experiment, the sample size was calculated with a type I error set at 0.05 ($\alpha=0.05$), a type II error set at 0.20 ($\beta=0.80$), the difference in population means and the standard deviation were deduced from a preliminary study. Differences between CWL and EWL were calculated. Data set were tested for the normality of the distribution by means of the Kolmogorov-Smirnov test and by Q-Q normality plots; thereby, the Wilcoxon test was chosen to assess the significance of the differences between EALs and apex width. All analyses were performed using the software Statistical Package for Social Sciences version 15 (SPSS® Inc., Chicago, IL, USA). A p value lower than 0.05 was regarded as statistically significant.

Results

Frequencies of the discrepancies between CWL and EWL are summarised in Table 1. Within an accepted range of ±0.5 and ±1.0 mm from CWL, the registered accuracies were 79.7% and 98.4% (Apit/intact tooth); 82.8% and 96.9% (Apit/simulated EARR); 81.3% and 98.4% (Root ZX/intact tooth); 76.6% and 96.9% (Root ZX/simulated EARR). No statistically significant differences between the accuracy of the EWL readings provided by the two EALs were observed (p > 0.05). EWLs did not significantly vary before and after EARR simulation (p > 0.05) regardless of the EAL used.

EWL mean values were found to be minimally shorter than CWLs; mean discrepancy values were: -0.3±0.5 (Apit/intact tooth); -0.2±0.5 (Apit/simulated EARR); -0.3±0.5 (Root ZX/intact tooth); -0.2±0.6 (Root ZX/ simulated EARR). Box and whisker plots reported in figure 2 show the difference, in mm, between the CWL and the EWL measured with the tested EALs.

Discussion

Correct WL determination is critical to achieve clinical success, allowing to clean, shape and fill the canal system as close as possible to the apical constriction and the maximum endodontic success rate is obtained when canal obturation lies within 2 mm of the radiographic apex [Gordon and Chandler, 2004]. The measurement of WL is traditionally made by means of multiple radiographic controls and more recently using EALs as well. Such devices, along with a preliminary
radiographic analysis, have provided a higher accuracy if compared to the use of intraoral radiography alone [Gordon and Chandler, 2004]. The most appropriate technique to determine in vitro the exact position of the apical constriction is histological dissection. However, among the non-destructive methods, the reference standard method we used to determine CWL seemed to be sufficiently precise, since the tip of the file was placed close to the apical constriction. Some authors suggest a 1 mm retraction of the file tip that is seen at the apical foramen [Pascon et al., 2009]; however, in anterior teeth the mean apex to foramen and apex to constriction distances are 0.38 mm and 0.89 mm respectively [Dummer et al., 1984]; therefore, we shortened 0.5 mm the CWL.

Under the conditions of the present study, the procedure to simulate EARR did not significantly affect the accuracy of the considered electronic devices, even making use of small-sized files in a 0.90 mm wide apical foramen. An overestimation of the WL was found in a very restricted number of specimens after EARR simulation. Contrariwise, ELAyouti et al. [2005] reported the risk of premature readings when using EALs in root-end resected teeth, but, differently from the present study, their measurements were performed in canals shaped with rotary files using saline solution as embedding medium, which appears to be less representative of the clinical conditions. When EALs are tested in vitro, a system that could simulate the impedance values of hard and soft oral tissues is needed [Baldi et al., 2007]. Alginate has been preferably chosen by many authors [Kaufman et al., 2002; Baldi et al., 2007; Bernardes et al., 2007; Herrera et al., 2007; Kang and Kim, 2008]. Different alginate models have been described in literature; all of them are based on the constancy of the relationship between the impedance value of the oral mucosa and deep periodontal tissues [Baldi et al., 2007].

While some authors found that instrument size of hand file does not influence the accuracy of in vitro EWL determination [Cianconi et al., 2010], others pointed out that, in enlarged canals, a file that has a tight fit with the canal walls at the apex provides more precise readings in comparison to files with a small diameters [Herrera et al., 2011]. In our study, after EARR simulation, the apical diameter of the canal was at least 0.90 mm wide, but the canal diameter can be even wider at this level of the root in single-rooted teeth [Wu et al., 2000]. Orthograde canal preparation was intentionally not performed to imitate the clinical condition of an untreated tooth with EARR, in order to simulate the first step that the clinician makes when performing a root canal treatment. Considering that we used a size 10 K file and that the coronal and middle thirds of the canal were untreated, the canal walls might have stabilized the file, preventing it to pass beyond the apex and allowing precise readings even in presence of simulated EARR. In accordance with our findings, some authors did not observe significant reduction of EALs accuracy in teeth with wide canals [Nguyen et al., 1996]. However, other studies [Ebrahim et al., 2006; Herrera et al., 2007] reported that wide root canals adversely affect EWL measurement. Nevertheless, it must be emphasised that it is difficult to summarise and compare the results obtained in different studies on wide canals/open apices because of a lack of method standardisation. Several differences in the study design are observable amongst the previously published studies [Herrera et al., 2011], such as sample selection, reference method, canal shaping protocol, apical diameter, endodontic file size or simulation of the resorption process.

Root ZX and Apit are third-generation devices that use multiple frequencies in impedance measurement [Dunlap et al., 1998], whose accuracy has been largely documented [Dunlap et al., 1998; Kaufman et al., 2002; Ebrahim et al., 2006; Bernardes et al., 2007; Kang and Kim, 2008; Cianconi et al., 2010]. Both devices operate at 2 different frequencies: Root ZX adopts 8 and 400 Hz [Venturi and Breschi, 2007] and calculates a quotient of impedances [Cianconi et al., 2010], whilst Apit works at 1,000 and 5,000 Hz and measures the difference between the two impedances [Lauper et al., 1996]. In spite of these differences in functioning design, similarly high accuracy levels were obtained by using the two devices, according to the data of several studies reported in the review by Gordon and Chandler [2004] and in a more recent study that compared the two devices [Cianconi et al., 2010]. EWL values within a range of ±0.5 mm are generally accepted, as they satisfy clinical requirements [Kang and Kim, 2008]. The underestimation the EALs generally provided in relation to CWL was negligible and cannot be considered clinically relevant. Such an underestimation depends on the fact that the reference method is standardised, but remains empiric and based on average anatomic values, while EWLs are determined through direct measurement, so that an overestimation of the CWL method is possible.

Though the radiographic examination is only capable of giving an estimate of the location of the apical constriction, there is global agreement that prior to endodontic treatment at least one undistorted radiograph is essential to assess the canal anatomy, the presence of periapical disease and to obtain preliminary information about the WL [Gordon and Chandler, 2004]. Periapical radiographs usually estimate a longer WL than the actual canal length [Kaufman et al., 2002], because the apical terminus is difficult to locate on the radiograph [ELAyouti et al., 2005]; the highest level of accuracy is achieved combining the use of a preoperative periapical radiograph and an EAL [Gordon and Chandler, 2004]. However, careful consideration must be given to the possibility of
reducing the radiation dose for the patient by limiting the number of radiographs during an endodontic treatment, particularly in case of therapies performed on children and adolescents. Furthermore, fixed metal orthodontic appliances may hinder the execution and the interpretation of the radiographs. For these reasons, the high accuracy provided by EALs in teeth with simulated postorthodontic EARR demonstrated by the present study has relevant clinical implications. Given that a postoperative radiograph is useful in order to check the proper canal filling and exclude the possibility of uncontrolled extrusion of endodontic materials, the findings of the present study support the use of EALs in teeth with EARR and the subsequent reduction or abolition of the need of intraoperative radiographs. In fact, in the majority of the cases an intraoperative radiograph is in some way a confirmation of what is already known by the endodontist [Gordon and Chandler, 2004]. On the other hand, a more rational and prudent approach aims to limit the radiation dose in young patients and to spread the use of harmless highly-accurate tools to minimise the risk of over- and underfilling [Gordon and Chandler, 2004].

Conclusion

The present in vitro study demonstrated that EALs are reliable devices even in case of simulation of a root resorption that may occur after comprehensive orthodontic treatment and they represent a valid alternative to intraoperative conventional radiographs. The possibility of limiting the radiation dose in young patients must always be considered. Apit and Root ZX apex locators were similarly accurate in WL determination both in case of intact and resorbed apex.

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