A Standardized Novel Method to Measure Radiographic Root Changes after Endodontic Therapy in Immature Teeth

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Abstract

Introduction: Outcome studies of endodontic treatment of necrotic immature permanent teeth rely on radiographic measures as surrogates of whether the treatment achieved regeneration/revascularization/revitalization. An increase in radiographic root length and/or width is thought to result in a better long-term prognosis for the tooth. In this study, a method to measure radiographic outcomes of endodontic therapies on immature teeth was developed and validated. **Methods:** A standardized protocol was developed for measuring the entire area of the root of immature teeth. The radiographic root area (RRA) measurement accounts for the entire surface area of the root as observed on a periapical radiograph. Reviewers were given instructions on how to measure RRA, and they completed measurements on a set of standardized radiographs. **Results:** The intraclass correlation between the 4 reviewers was 0.9945, suggesting a high concordance among reviewers. There was no effect of the reviewer on the measured RRA values. High concordance was also observed when 1 rater repeated the measurements, with an intraclass correlation value of 0.9995. There was no significant difference in RRA values measured at the 2 sessions by the same rater. Furthermore, significant differences in RRA were detectable between clinical cases that showed obvious continued root development and cases that did not demonstrate discernible root development. **Conclusions:** These results suggest that RRA is a valid measure to assess radiographic outcomes in endodontically treated immature teeth, and RRA should be useful in future clinical studies of regenerative endodontic outcomes. *(J Endod 2014;40:46–50)*

Key Words

Clinical outcomes, radiographic analysis, radiographic root area, regenerative endodontics, revascularization, revitalization

The development of improved methods to treat immature necrotic teeth with open apices has been of considerable interest in endodontics in the past decade. Traditional treatment options include apexification with long-term intracanal calcium hydroxide or the placement of a mineral trioxide aggregate (MTA) apical barrier before obturation of the root canal system (1). However, these treatment options result in a guarded long-term prognosis because of thin dentin walls, an incompletely formed apex, and in some cases short roots (2–5). Furthermore, extraction is a poor alternative because replacing the lost tooth with an implant or fixed partial denture is contraindicated in young patients because of the mixed dentition status and ongoing cranioskeletal development. Treatment methods variously termed "revascularization," "revitalization," or "regeneration" have become increasingly popular in endodontics. Although it is unknown if these procedures truly regenerate the pulp-dentin complex in patients, the term "regenerative endodontics" is often used to describe these procedures, is recognized by the American Association of Endodontists, and is widely used in the endodontic literature (6, 7). An advantage of regenerative endodontic treatment is further development of the root structure in the immature tooth (8). Increased thickness of the root dentin walls is believed to increase the long-term resistance to vertical root fracture for these teeth (9, 10). In addition, the regenerative endodontic procedure promotes apical closure, which will allow conventional nonsurgical root canal therapy to be performed should the tooth require endodontic therapy in the future.

To date, the published research on the outcomes of regenerative endodontic therapies includes a limited number of case series and retrospective studies (3, 11–14). These studies have all used radiographic measures as surrogates to assess the success of treatment on hard tissue deposition and to compare the success of different treatments. Similarly, radiographic outcomes are routinely used in endodontic outcome studies after both nonsurgical and surgical endodontic therapy in mature teeth (15, 16). The rationale for using a radiographic outcome measure in regenerative endodontic studies is that an increase in radiographic root length and/or width is likely to result in greater resistance to root fracture (a common cause of eventual loss of teeth treated with calcium hydroxide apexification or an MTA apical barrier). It should be noted that although it is assumed that the increased root length or width is caused by pulpal regeneration and new dentin deposition, the nature of the tissue formed in the tooth cannot be known with certainty without adequate histologic analysis.

Bose et al (11) published a retrospective evaluation of radiographic outcomes of cases after regenerative endodontic or control treatments. Preoperative and postoperative radiographs were analyzed in ImageJ (National Institutes of Health, Bethesda, MD),

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and the plug-in application TurboReg (Lausanne, VD, Switzerland) was used to mathematically correct for differences in angulation between the preoperative and postoperative images. The root length from the cementoenamel junction to the root apex and the dentin thickness at the apical one third of the root were measured. Using this method, differences in root length and width between treatments were detectable. Subsequent studies of regenerative endodontic outcomes have used this same method of measuring root length and width (3, 13). Although this method was able to detect differences between groups, it does have limitations because it measures dentin thickness at only 1 level of the root. Furthermore, it is unknown if root length or width is a more important measure to predict clinical outcome and at which level of the root the width is the most important. Chen et al (12) also reported a radiographic assessment of outcomes; cases were qualitatively scored for healing of the periapical lesion, thickening of the canal walls, and significantly continued root development. The authors summarized 5 types of responses to regenerative endodontic treatment as observed radiographically in these teeth. In another retrospective study, Chueh et al (14) recorded the final apical shape of the teeth after treatment. However, qualitative scoring systems are unlikely to have the desired sensitivity for use in future studies to compare outcomes between treatments.

The purpose of this study was to develop and validate a method to measure radiographic outcomes of endodontic therapies on immature teeth. The radiographic root area (RRA) measurement accounts for the entire surface area of the root as observed on a periapical radiograph. RRA offers advantages over previously used radiographic outcomes methods, and we suggest that it will be useful in future clinical studies of regenerative endodontic outcomes.

Methods

Measurement of RRA

Multiple individual radiographs were used to measure the RRA using the freeware ImageJ (version 1.47). In ImageJ, the polygon tool was used to outline the total root area bordered on the occlusal aspect by the mesial and distal cementoenamel junction and peripherally by the periodontal ligament space (Fig. 1*A* and *C*). The measurement function yields a value that reflects the entire planar area of the root. To account for the space taken by the root canal system, the polygon tool was again used to outline the root canal space (Fig. 1*B* and *D*), and the measurement for the area was obtained. The RRA measurement was calculated as the difference between the total root area and the root canal space in each radiograph.

Reproducibility of RRA Measurements

To measure inter-rater reliability, 4 investigators (N.M.F., A.A.K., J.L.G., A.D.) independently calculated RRA on 18 radiographs that were preoperative and follow-up radiographs of immature permanent teeth treated endodontically. Three investigators followed written instructions on how to perform the RRA measurements, and one had experience performing the measure previously (A.D.). To measure intrarater reliability, 1 investigator (N.M.F.) remeasured RRA on 18 radiographs more than a year after the initial measures were taken. Reproducibility was assessed by calculating intraclass correlation (ICC) values. This is a measurement of concordance, similar to kappa values, but can be used for continuous variables such as area. The ICC was calculated using an online calculator (see Statistical Analysis).

RRA in Test Set of Radiographs

To test the validity of RRA as an outcome, we calculated the RRA in preoperative and follow-up radiographs in a series of cases that were selected based on whether the case clearly showed continued root development in the follow-up radiograph or not. Seven cases were selected in each group. All cases in the positive root growth group were treated by regenerative procedures. The control cases that were selected based on not showing any discernible root growth on follow-up were either treated by regenerative procedures (5 cases) or MTA apexification (2 cases). The preoperative and follow-up radiographs in each case were normalized to each other using the TurboReg plug-in tool (Philippe Thévenaz, Biomedical Imaging Group, Swiss Federal Institute of Technology Lausanne, Lausanne, Switzerland) with the ImageJ software program to minimize distortions caused by variability in the angulation when the radiographs were acquired (11). The percent change in RRA was then calculated for each case.

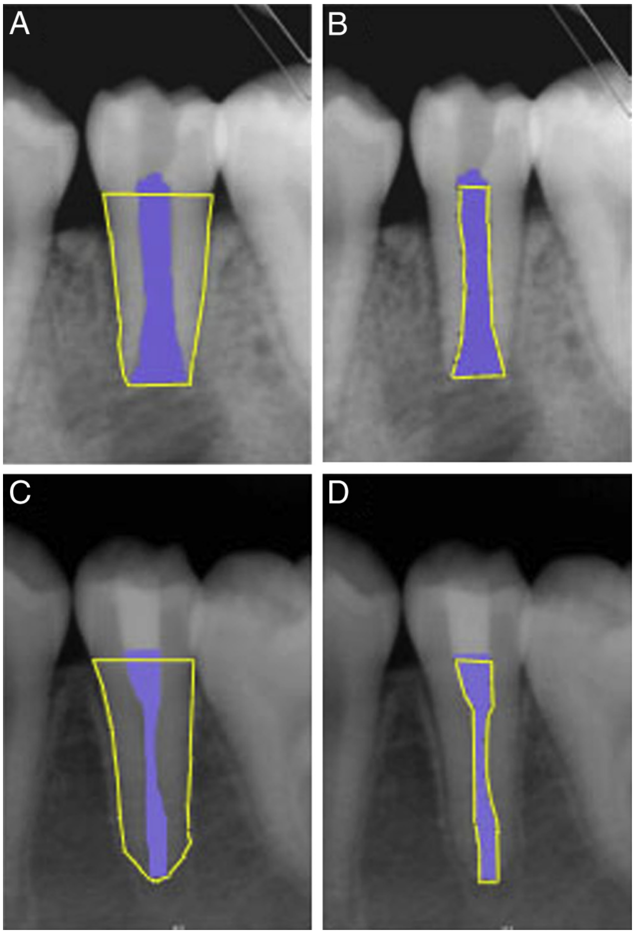

Figure 1. Instructional images for performing radiographic root area measurements in ImageJ. For demonstration purposes, the canal space of the images was masked with a purple color. This may be used to blind observers when needed. (*A*) A masked preoperative radiograph showing outlining of the total root area. (*B*) A masked preoperative radiograph showing outlining of the canal space. (*C*) A masked follow-up radiograph showing outlining of the total root area. (*D*) A masked follow-up radiograph showing outlining of the canal space.

Statistical Analysis

Differences between groups were assessed by 1-way analysis of variance (ANOVA) (inter- and intrarater reliability) and the Student *t* test (2-group comparison of percentage change in RRA) (GraphPad Prism 5.0 for Mac OSX, 2010; GraphPad Software, La Jolla, CA). Concordance was measured with ICC values using an online calculator (Department of Obstetrics and Gynecology, The Chinese University of