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Observations of Trends and Successes of Revascularization Therapy at Virginia Commonwealth University: A Retrospective Study

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Observations of Trends and Successes of Revascularization Therapy at Virginia Commonwealth University: A Retrospective Study

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University

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Abstract

OBSERVATIONS OF TRENDS AND SUCCESSES OF REVASCULARIZATION THERAPY AT VIRGINIA COMMONWEALTH UNIVERSITY: A RETROSPECTIVE STUDY

By Richard W. Sedwick, DDS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

Virginia Commonwealth University, 2018

Director: Dr. Garry Myers, DDS
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The aim of this study was to determine the trends in protocol, success rates, and consistency in follow up of revascularization procedures in a controlled environment. Patients of the Virginia Commonwealth University School of Dentistry were identified who were offered revascularization therapy as a treatment option on immature permanent teeth from January 1, 2010 to May 31, 2017. A total of 77 patients and 78 teeth were evaluated for revascularization therapy. For patients accepting treatment, records were reviewed for outcome assessment and consistency of follow up. A total of 30 patients (31 teeth) were treated following revascularization protocols, with only 20 patients (21 teeth) returning for follow up. Six of the 21 teeth needed some form of additional therapy due to patients remaining symptomatic, however 15/21 exhibited varying levels of success. Recall rate was 67.7%. With a success rate of 71.4%, revascularization therapy should continue to be considered for all patients with teeth having

necrotic pulps and immature root apices. However, changes to recall protocols need to be improved in order to better monitor the status of teeth that undergo revascularization therapy.

Introduction

Scientific progress has improved the quality of life over the last century, with tremendous advances occurring over the last 20 to 30 years, including the engineering of new tissue for failing organs and tissues. Tissue engineering emerged in the late 1990's as a new way to help reduce costs for patients and the health care system by using stem cells, growth factors, and scaffolds to form new and functional tissue. Recreating functional tissue from a patient's own stem cells would lessen the burden for outside donors, decrease medication costs, and lower the cost of surgical procedures (1). In addition to physicians, dentists are also interested in reengineering dental tissues, with a current focus on regenerative pulpal therapy.

Understanding regenerative pulp therapy requires a brief overview of the formation of the pulp-dentin complex. The dental pulp forms from the cephalic neural crest, which arises from the ectoderm of the lateral borders of the neural plate. The neural crest cells become the dental lamina which subsequently differentiates into the ectomesenchymal cells and the dental papilla. Growth factors promote proliferation, migration, and differentiation of the ectomesenchymal cells. The developing cluster of cells undergo changes known as the bud, cap, and bell stages. During the bell stage, the dental papilla becomes enveloped by the invaginating enamel epithelium (2). Kettunen demonstrated that the trigeminal nerve ganglia act as the contributor of the sensory nerves of the tooth, and that the timing of tooth nerve development is not random, but rather a carefully timed process (3). Throughout the cap and bell stages, a network of nerves forms beneath the developing tooth and are allowed to enter the dental papilla only after the coronal shape appears. This occurs after both dentin and enamel are present within the crown, as has been shown in mouse models (4,5).

Key cells in the pulp include the odontoblasts and the fibroblasts. Odontoblasts line the edge of the pulp-dentin complex, where they are found in higher numbers coronally with decreased amounts in the radicular area of the tooth. Odontoblasts are key to both root thickening and development as they lay down dentin in the developmental process (2). Fibroblasts are the most plentiful cells of the pulp and are responsible for both collagen production and turn over within the pulp. Additionally, fibroblasts are thought to give rise to odontoblast-like cells if given the proper signal (2). Fibroblasts assist with wound healing by releasing proinflammatory cytokines and either stimulating the odontoblasts or differentiating into odontoblast like cells (6). Development of the tooth and key cellular components are important components in regenerative endodontics.

Historically, dentists have been on the cusp of regenerative therapy for the dental pulp. In 1952 Hermann attempted to use calcium hydroxide for vital pulp therapy in the damaged dentition. Additionally, Nygaard-Ostby studied the role of the blood clot in revascularization of the pulp complex during the 1950's and 1960's. Nygaard-Ostby studied both human and animal models with vital and necrotic teeth. Protocols used in his study laid important ground work for future regenerative pulp treatments, especially in regard to rinsing with EDTA (7). Since that time, advances in the understanding of pulp biology have established protocols in regenerative endodontics.

Current studies of regenerative endodontics have focused on revascularization. The American Association of Endodontists (AAE) has four main objectives for successful revascularization procedures. First, the tooth must be asymptomatic and functional. Second, within the first 6-12 months there should be resolution of the periradicular radiolucency and possible thickening of the dentinal walls. Third and fourth, between 12 and 24 months definitive increase in dentin wall thickness and an increase in root length (8). The process to achieve these goals has narrowed current research to focus on proper disinfection of the compromised root canal system and stem cell recruitment for differentiation into the cells necessary for continued root development. Subsequently, a scaffold is needed to provide a framework for the newly enlisted cells, and mediators are necessary to prompt their differentiation. Proper case selection is also important in the revascularization procedure, with current modalities only focusing on the necrotic pulp with open apices in immature permanent teeth.

Irrigants

For revascularization procedures when debriding the root canal space in immature permanent teeth with necrotic pulps, irrigants are relied on rather than mechanical debridement. In 2001, Iwaya et al first described a process for a revascularization technique that refrained from using mechanical instrumentation of the root canal but rather opted for irrigation with 5% sodium hypochlorite (NaOCl) and 3% hydrogen peroxide. The process was completed over 5 visits, which, in addition to rinses with NaOCl and 3% hydrogen peroxide also consisted of a placement of a mixture of metronidazole and ciprofloxacin (9). Banchs and Trope published a similar case study in 2004, where their irrigation protocol was based off of Iwaya's work, but instead of 3% hydrogen peroxide, Peridex was used (10). In contrast to Iwaya, Banchs and Trope irrigated at the first appointment and added minocycline to the antibiotic paste placed within the canal. Additionally, Banchs and Trope's case was completed at the second appointment because the patient was asymptomatic and there was already evidence of radiographic healing at 26 days.

In both of these case reports the canals were not instrumented, with the rationale stated by Iwaya that since there may have “been some vital pulp tissue in the canal, the root canal was not cleaned to its full length (9).” This rationale has persisted into the most recent protocols as outlined by the AAE (8,11). Both in the case of Banchs and Iwaya, an endodontic instrument was later introduced into the canal where vital tissue was stimulated. In the case of Iwaya, the tissue was 5 mm below the CEJ and elicited a painful response on probing, and in Banchs’ case, bleeding was induced at a second visit from tissue 15mm inside the access of the tooth in the case report (10).

Researchers later questioned which irrigants would have the greatest positive effect on the revascularization process and how stem cells would adhere to the dentin within the canals. Ring et al looked at 10 different endodontic irrigants and chelating treatments and how they affected the adhesion of dental pulp stem cells (DPSCs). Their findings concluded that removal of the smear layer was not entirely necessary and that common irrigants like NaOCl and EDTA were suitable for disinfecting and preparing the root canal dentin (12). Martin et al found that a lower concentration of NaOCl (1%) followed by a 17% EDTA rinse protocol was optimal when tested on stem cells of the apical papilla (SCAPs) relative to their survival and differentiation (13). Trevino had similar findings with SCAPs and irrigants, noting that EDTA may have more beneficial effects in a platelet rich plasma (PRP) scaffold (14). In a study published in 2011, Galler et al utilized dentin discs and cylinders embedded with DPSCs and implanted in mice. Prior to embedding the DPSC into the dentin delivery devices, the discs and cylinders were either rinsed with 5.25% NaOCl or 17% EDTA. Galler et al found that in the EDTA group, the stem cells were found in close approximation with the dentin and forming into odontoblast-like cells. Galler also recognized that the use of NaOCl was important for disinfection (15). Based off these and similar findings, the AAE currently recommends an initial rinse with 20 ml per canal of 1.5% NaOCl over 5 minutes followed by either a rinse of 17 % EDTA (20 ml per canal) over 5 minutes or a rinse of saline. Once the canal is dried with paper points, the clinician then must decide on an inter-appointment medicament (11).

Inter-appointment Medicaments

For these early revascularization procedures, antibiotic pastes were used in the root canal space as an inter-appointment medicament. Iwaya used a mixture of metronidazole and ciprofloxacin, while Banchs and Trope used a combination of metronidazole, ciprofloxacin and minocycline (9,10). Following in the footsteps of these pioneers of regenerative endodontic therapy, other clinicians have followed suit in treating these cases with either double antibiotic paste (DAP) or triple antibiotic paste (TAP). Because DAP and TAP are not typically kept in dental offices, clinicians have also looked at using calcium hydroxide (CaOH). Research is ongoing to determine the effects of these inter-appointment medicaments on dentin and the deposition of stem cells on the dentinal wall along with ingrowth of vital tissues.

Ruparel et al conducted a study on freshly harvested SCAPs from immature third molars. These cells were placed in wells and then treated with a medium as a control, TAP, DAP, CaOH, Augmentin, and a modified TAP (mTAP) that used cefaclor rather than minocycline (16). Various concentrations of antibiotics and CaOH were tested. Ruparel et al found that all of the antibiotic pastes in higher concentrations led to a decreased survivability of SCAPs. Lower concentrations did not have a significant impact on stem cell survivability. Interestingly, at all concentrations, the CaOH promoted cell survival. In 1996, Sato et al studied the effects of TAP following ultrasonic irrigation with EDTA. Extracted teeth were inoculated with bacteria following the EDTA rinse and the canals were treated with saline as a control or TAP and sampled at 5 hours, 24 hours, and 48 hours. Sato found that no bacteria was found after 48 hours in the TAP group (17). In two additional trials with slightly differing testing methods, the results were similar. Sato concluded that TAP was both antibacterial and able to penetrate the dentin. Windley et al also studied TAP in a canine study where premolars were purposely infected with oral plaque biofilms. Sampling of the teeth occurred before and after irrigation and after placement of TAP (18). Windley found that TAP was effective in disinfecting the canal of the immature tooth for regenerative endodontic procedures. Gomes-Filho et al in Brazil found that TAP and CaOH were biocompatible in the radicular dentin (19). Contradictory findings by Yassen et al found that both TAP and CaOH led to collagen degradation and demineralization in the radicular dentin (20).

One important distinction between the use of triple antibiotic paste and the use of CaOH is color change within the dentin. Kim et al presented a case report where a maxillary central incisor was treated with TAP during the regenerative endodontic procedure. Six weeks following placement of the antibiotic paste, the patient reported to the office complaining of a blue-gray hue to the treated tooth. Even after 3 treatments of walking bleach, the tooth was still blue-gray in the cervical area (21). As a result of this case report, Kim studied the discoloration of maxillary and mandibular molars treated with the minocycline from the TAP, finding that this antibiotic did lead to significant dentin discoloration. Thibodeau and Trope presented an early case report where the minocycline was replaced with cefaclor, yielding favorable healing results (22). The AAE currently recommends placing TAP below the CEJ to avoid this discoloration or using substituting another antibiotic in place of minocycline (11). These findings are important to note when selecting a medicament after irrigation and prior to stem cell recruitment.

Stem Cells

During the second visit of a regenerative endodontic procedure, the TAP or CaOH is rinsed away with 20 ml of 17% EDTA and the canal dried with paper points (11). Stem cells are then recruited to the canal space. Several different types of stem cells have been identified: Dental Pulp Stem Cells (DPSCs), Stem Cells of Human Exfoliated Deciduous Teeth (SHED), Stem Cells of the Apical Papilla (SCAPs), Dental Follicle Progenitor Cells (DFPCs), and Bone Marrow-derived Mesenchymal Stem Cells (BMMSCs) (11). In 1997, Prockop described what he called Marrow Stromal cells, which were non-hematopoietic multipotent cells that could differentiate into osteoblasts, chondroblasts, adipocytes, and myoblasts (23). Prockop proposed that one usage for BMMSCs would be to infuse the cells in an area where they can differentiate into the cell type desired. One of the major draw backs of BMMSCs would be harvesting them and the pain associated with healing of the extraction site.

Dental pulp stem cells (DPSCs) are collected from the pulp of human teeth. They can be harvested from extracted teeth and are known for their ability to form a dentin-pulp like complex. DPSCs will not proliferate past twenty rounds of doubling, meaning the cell line has a finite endpoint which makes them difficult to culture in large amounts. However, Gronthos argues that the cell lines are worth studying in regeneration models (24). Stem cells of the human exfoliated deciduous teeth (SHED) were studied by Miura and found to be multipotent stem cells capable of differentiating into neural cells as well as odontoblasts. SHED were also found to be able to differentiate into both bone and dentin. Miura does point out that the cells are more difficult to obtain but have excellent capability to differentiate and should be studied further for use in revascularization procedures (25).

Dental follicle progenitor cells (DFPCs) are derived from the sac of cells around the developing, unerupted tooth. Morsczeck et al studied these cells by removing cells from this sac of freshly extracted developing teeth. Cells were cultured over time and allowed to proliferate and differentiation was possible for cementoblasts, osteoblasts, and periodontal ligament cells. Morsczeck et al felt that due to the amount of third molar extractions, DFPCs are a viable source of stem cells (26).

Sonoyama et al at USC were some of the first to report usage of stem cells of the apical papilla (SCAPs) in regenerative endodontic procedures. Using transplanted human tissue in pig models, Sonoyama were able to see an increase in dentinal root length and strength (27). Huang et al compared DPSCs and SCAPs for their abilities to proliferate and differentiate within the canal space. Both cell lines were found to migrate to the dentin surface and differentiate into odontoblast-like cells and lay down dentin-like material (28). Applying these ideas, Lovelace et al induced bleeding at the apex of 12 immature root apices in patients needing revascularization/regenerative endodontic procedures. Using DNA markers, researchers found that mesenchymal stem cells do proliferate into the canal space (29). Additionally, SCAP have been shown to maintain vitality when there is inflammation of the apical papilla, even showing an increase in osteogenic and angiogenesis potential (29). Currently, the AAE recommends following the protocol of Lovelace, et al and inducing bleeding from the apical foramen by instrumenting 2 mm out the apex of the tooth and forming a blood clot up to just below the CEJ (11).

Scaffolds

The scaffold is a medium for the stem cells to gain nutrients and signaling molecules for the proliferation and differentiation of stem cells (31). Kontakiotis et al reviewed current endodontic procedures, identifying induction of a blood clot, use of plasma rich protein (PRP), or plasma rich fibrin as the three main types of scaffolds used in revascularization (32). Interestingly, in his review, 13% of cases did not even mention which type of scaffold was used in the regenerative endodontic procedure. As mentioned previously, the earliest and most common scaffold used is the induction of bleeding and formation of a clot in the canal space in a second visit during the regenerative endodontic process, as described by Iwaya and Banchs (9,10). The PRP scaffold was first described in a case report by Torabinejad in 2011 (33). PRP was derived from a 20 ml sample of blood taken from the patient's forearm. Trevino et al found that NaOCl and EDTA allow SCAPs to proliferate on the plasma rich protein (PRP) scaffold (14). Kim et al detail the different growth factors potentially involved in signaling stem cells in the pulp chamber, including platelet derived growth factor (PDGF), transforming growth factor (TGF), bone morphogenic protein (BMP), and vascular endothelial growth factor (VEGF), among others (34). Zeng et al found that irrigation protocols already discussed also lead to the release of growth factors such as TGF and VEGF from the dentin (35).

Other scaffolds have been suggested for use in revascularization. Ray et al identified plasma rich fibrin as a scaffold for stem cells. Blood was drawn and passed through a centrifuge and the plasma layer was removed and cut into segments and placed in the canal after bleeding was induced at the apex (36). Additionally, Combria et al recommended a sodium hyaluronate and chitosan scaffold seeded with stem cells as a potential alternative method studied in animal models (37).

Moving Forward

Continued research is needed in many areas of regenerative endodontic procedures. More information is needed on the induction of signaling molecules and the timing of their release. To truly have regeneration and not revascularization, further understanding of how stem cells differentiate into odontoblasts and not just odontoblast-like cells needs to be closely researched. Other innovations include the use of new synthetic scaffolds like sodium hyaluronate and chitosan which can be implemented with a timed release of cell mediators. Additionally, the procedure of revascularization needs further long-term studies, as the earliest case reports are from 2001, so long term analysis is unavailable. Current protocols are from 2011, therefore standardization of procedures has not been a clinical norm. As Kontakiotis indicated, reporting of protocol needs to be standardized as well (32). The aim of this study was to analyze revascularization procedures done at Virginia Commonwealth University School of Dentistry, where proper adherence to AAE protocols should be followed with adequate reporting and follow up. The ultimate goal of this thesis is to add to the body of research and assess the relative success rate of regenerative endodontic procedures in a controlled environment.

Materials & Methods

Patient records for this study were pooled from resident cases completed at Virginia Commonwealth University in the Graduate Endodontic department after approval from the Institutional Review Board at the university (HM20010146). Cases were selected from January of 2010 through May of 2017. In order to identify cases, a search of the VCU School of Dentistry's patient charting software, axiUm CE (LEADTOOLS Technologies, ©2017), was performed using the codes established by the American Dental Association (ADA) and the American Association of Endodontists (AAE) in 2013 for regeneration procedures – D3355, D3356, and D3357, as well as D3999 for patients seen before the introduction of the CDT codes. Additionally, a key word search was performed for the following terms within chart notes from the prescribed time period: regeneration, regenerative, and revascularization. Between the two search techniques, 484 notes and 258 different coded patients were identified. Once redundant patient charts and those identified as cases pertaining to periodontal procedures were eliminated, 78 cases were identified and reviewed as potential candidates for this study (see Appendix ZZZ).

Cases that filled the following criteria were included for analysis:

1. Permanent tooth with immature root formation treatment planned for revascularization.
2. Permanent tooth with immature root formation that was treated with revascularization protocols from start to finish.
3. Cases that had at least one follow up appointment with documentation of symptoms.

Cases were excluded if there was a change of treatment protocols from regenerative therapy to another treatment type, either vital pulp therapy, apexification or non-surgical root canal therapy during the initial treatment phase. Of the 78 cases where patients were offered regeneration, 27 opted for another treatment option - 17 of which had MTA apexification, 2 had BC putty apexification, 5 had NSRCT, and 3 were extracted. Additionally, 8 teeth had an incorrect preoperative diagnosis and had vital pulp therapy once the tooth was accessed; 9 were lost after the initial treatment planning visit, and 3 opted to do nothing or watch the tooth and saw positive pulpal responses. Thirty-one teeth were treated following regenerative endodontic procedure protocols, however, almost one-third of these were lost to follow up. The final number of cases included within the parameters of the study was 21.

Additional information regarding the patient and case were recorded, such as age, sex, etiology precipitating treatment, pulpal and periapical diagnosis, intracanal medicament used, irrigation protocol, type of scaffold and method of tooth closure. Number of visits for treatment and number of recalls were also noted, and each case was then de-identified for outcome assignation. Historically and currently, all revascularization procedures have been completed following the AAE protocols (see Appendix 1), however, VCU does not have a specific protocol in place relative to choosing an intracanal medicament, number of needed appointments to treat a revascularization case, or establishing a recall schedule. Thus, medicaments used and follow up period varied and were included in this study as a potential means for measuring outcomes.

Outcome types were divided into 3 categories based on radiographic and clinical data on follow-up visits. Each case was assigned to one of the following groups as defined by Bukhari (38):

1. Complete healing: The absence of clinical signs and symptoms, complete resolution of periradicular radiolucency, and an increase in the root dentin thickness/length and apical closure.

2. Incomplete Healing: The absence of clinical signs and symptoms, the periapical lesion completely healed without any signs of root maturation or thickening, the periapical lesion either reduced in size or unchanged with/without radiographic signs of increasing root dentin thickness/length, or apical closure.
3. Failure: Persistent clinical signs and symptoms and/or increased size of the periradicular lesion.

A total of 3 boarded endodontists and 3 boarded pediatric dentists were calibrated to understand radiographic outcome determinants and asked to place each case into one of the three categories using a REDCap (© Vanderbuilt University) survey. Radiographic examples of each outcome were shown for normalization. If there was disagreement on outcome determination, discussion ensued until an agreement on outcome was reached by the primary authors of the study (RS and GM). An example of the calibration can be seen in appendix C in the initial 5 slides of the REDCap survey. Specialist evaluators graded radiographic healing only, without a knowledge of patient symptoms or knowledge of subsequent diagnostic testing.

Statistical methods

All data was gathered via chart review from the axiUm CE (LEADTOOLS Technologies, ©2017) program, with all data placed into an Excel (Microsoft ©2015) spreadsheet. The data were described using counts and percentages. Associations were assessed using a chi-square analysis. All analyses were performed using SAS software (JMP version 13.2, SAS Institute Inc., Cary NC) and statistical significance was declared at the 5% level.

Results

The results of this study begin with a description of the teeth that were included for evaluation. Characteristics of the patients, the etiology of disease, pulpal and periapical status, and follow-up length are outlined. The next section highlights the healing status of teeth related to the different treatment factors. Finally, a description is made of the evaluators who determined radiographic healing status for the revascularized teeth and differences in the responses by the evaluators is shown.

Description of the Teeth

A total of 31 cases were initially identified from the time period between March 2010 and February 2017. Of these, 21 were available for follow-up and are included for analysis here. There were 16 males (one contributing two teeth) and 4 females. The median age was 9 years old (range = 6 to 16 years). Predominantly, the treated teeth were maxillary central incisors (N=7, 33% tooth 8; N=8, 38% tooth 9) but the following teeth were also treated: Tooth 3, 12, 20, 27 and 29 (see Table 1). The characteristics of the teeth at the time of the initial treatment are shown in Table 5. The primary etiology was trauma (71%). Primarily the pulpal diagnosis was pulp necrosis (81%) and the most typical periapical diagnosis was asymptomatic apical periodontitis (29%). Ca(OH)2 was the predominant intracanal medicament used (34%). One case was initially given a pulpal diagnosis of reversible pulpitis, however, on opening the pulp chamber, necrotic tissue was found.

Table 1. Teeth Included in the Study

Tooth Number	N	Percent
3	1	5
8	7	33
9	8	38
12	1	5
20	2	10
27	1	5
29	1	5

Table 2. Characteristics of the Teeth

Characteristic	N	Percent
Etiology		
Caries	3	14
Dens Evaginatus	2	10
Trauma	15	71
Unknown	1	5
Pulpal Diagnosis		
Asymptomatic Irreversible Pulpitis	1	5
Previously Initiated	1	5
Pulp Necrosis	17	81
Reversible Pulpitis	1	5
Symptomatic Irreversible Pulpitis	1	5
Periapical Diagnosis		
Acute Apical Abscess	3	14
Asymptomatic Apical Periodontitis	6	29
Chronic Apical Abscess	5	24
Normal Apical Tissue	3	14
Symptomatic Apical Periodontitis	4	19
Intracanal Medicament		
$Ca(OH)_2$	6	29
$Ca(OH)_2$, TAP	1	5
DAP	6	29
TAP	6	29

none	2	10

Abbreviations: DAP = Double Antibiotic Paste, TAP = Triple Antibiotic Paste.

The median follow-up visit occurred at 15 months and half of all the follow-up visits occurred between 7 and 32 months (range = 1 to 55 months). From the radiographs and charts, it was determined that 7 were instances of complete healing, 5 were cases of treatment failure, and in the remaining 9 there was evidence of incomplete healing. These status designations were created using the system illustrated by Bukhari and are described in the methods with each healing type illustrated in figures 1-3 (38). Broadly, those teeth classified within a healing category totaled 16/21 (76.2%) while the remaining failed teeth were 5/21(23.8%).

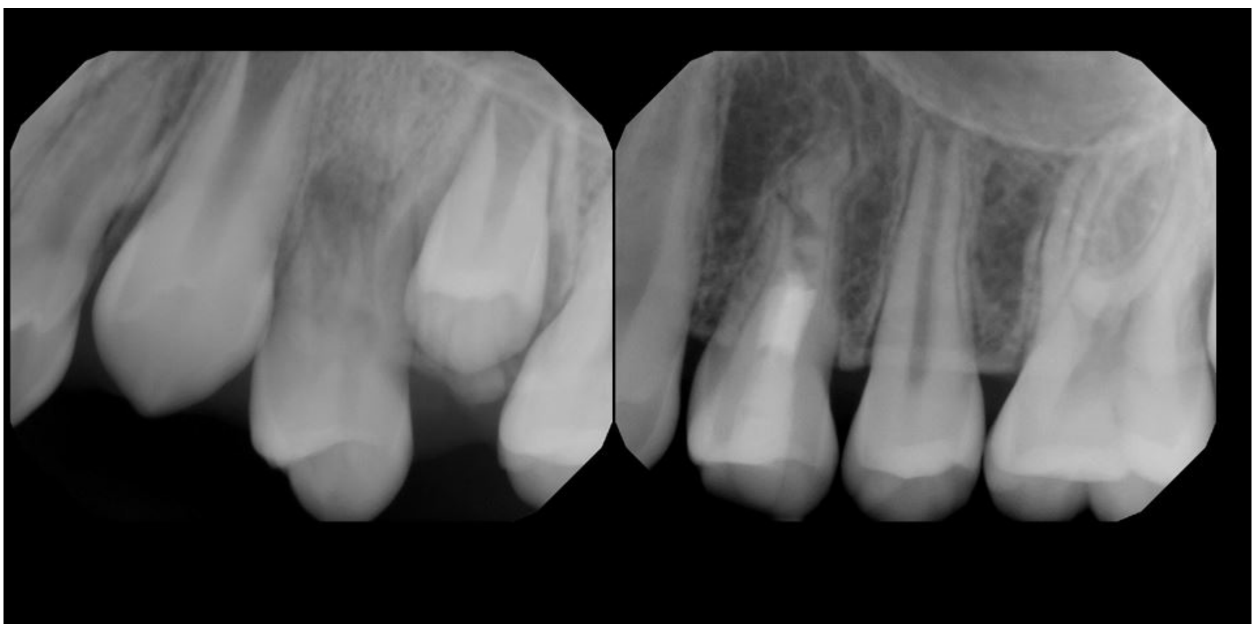

Figure 1 - Example of Complete Healing

Healing Status as Related to Treatment Factors

There was no indication of a relationship between tooth number and post-treatment healing status (chi-square p-value > 0.2, Table 3), although it was noted that all of the cases of incomplete healing occurred among the central incisors. There is some indication of a relationship of the patient characteristics to healing status (Table 4). In the case of etiology, all of the incomplete healing cases came about through trauma (chi-square p-value = 0.0736). Neither periapical diagnosis (p-value > 0.4), medicament (p-value > 0.3) nor follow-up months (p-value > 0.6) was related to healing status.

Table 3. Relationship between post-treatment healing status and tooth number

	Healing Status				
Tooth Number	Complete	Incomplete	Failure	Total	P-value*
3	1	0	0	1	0.2237
8	2	3	2	7	
9	1	6	1	8	
12	1	0	0	1	
20	1	0	1	2	
27	0	0	1	1	
29	1	0	0	1	
Total	7	9	5	21	

*P-value from chi-square test

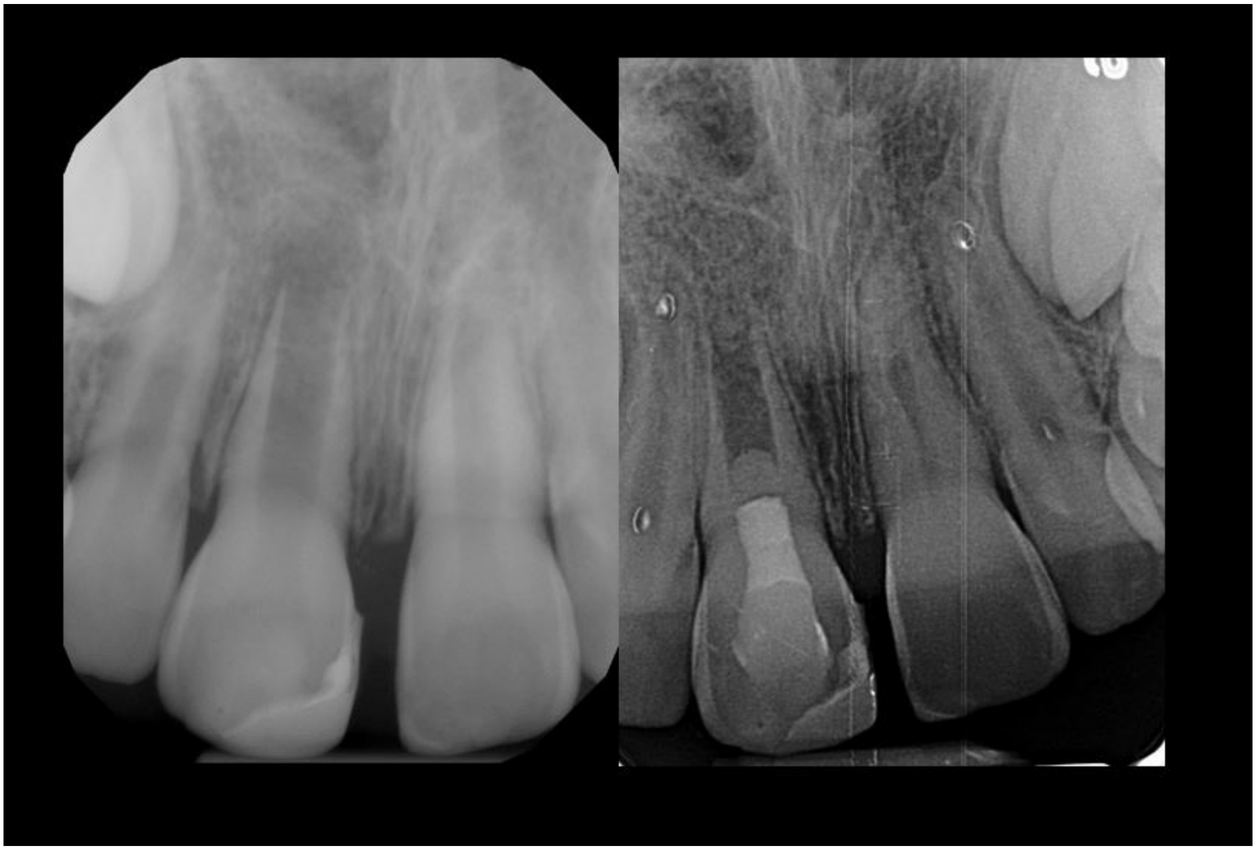

Figure 2 - Example of Incomplete Healing

Table 4. Relationship between post-treatment healing status and patient characteristics

	Healing Status				
Characteristic	Complete	Incomplete	Failure	Total	P-value*
Etiology					0.0736
Caries	2	0	1	3	
Dens Evaginatus	2	0	0	2	
Trauma	3	9	3	15	
Unknown	0	0	1	1	
Total	7	9	5	21	
Pulpal Diagnosis					0.4221
Asymptomatic Irreversible Pulpitis	0	1	0	1	
Previously Initiated	1	0	0	1	
Pulp Necrosis	4	8	5	17	
Reversible Pulpitis	1	0	0	1	
Symptomatic Irreversible Pulpitis	1	0	0	1	
Total	7	9	5	21	
Periapical Diagnosis					0.4062
Acute Apical Abscess	1	0	2	3	
Asymptomatic Apical Periodontitis	1	3	2	6	
Chronic Apical Abscess	2	2	1	5	
Normal Apical Tissue	2	1	0	3	
Symptomatic Apical Periodontitis	1	3	0	4	
Total	7	9	5	21	
Intracanal Medicament					0.3975
Ca(OH)2	1	3	2	6	
Ca(OH)2, TAP	1	0	0	1	
DAP	2	4	0	6	
TAP	2	1	3	6	
none	1	1	0	2	
Total	7	9	5	21	

*P-value from chi-square test

Description of Respondents and Respondent Selections

As specified in the Methods section, pre-treatment and follow-up radiographs were included in a REDCap survey. Respondents to the survey were asked for their assessment of healing for each of the 21 cases. There were 3 board certified Endodontists in the survey and 3 board certified Pediatric Dentist respondents. For each of the images the number of responses for each specialty type is shown in Table 5. For example, there was one Endodontist who rated Patient 1 as completely healed, three raters who correctly identified it as an instance of incomplete healing, and two Pediatric Dentists who indicated that the healing had failed to occur. As may be seen, the number of correct answers ranged from 1 rater out of six (patient 20) to a number of patients where all six raters agreed on the correct healing status (patients 6, 7, 8, 11, 12, 14, and 18). The three Endodontists correctly identified between 16 and 18 cases and the three Pediatric Dentists correctly identified between 15 and 17 of the 21 cases. Overall, the average was 16.7 correct (79%, SD = 1.03).

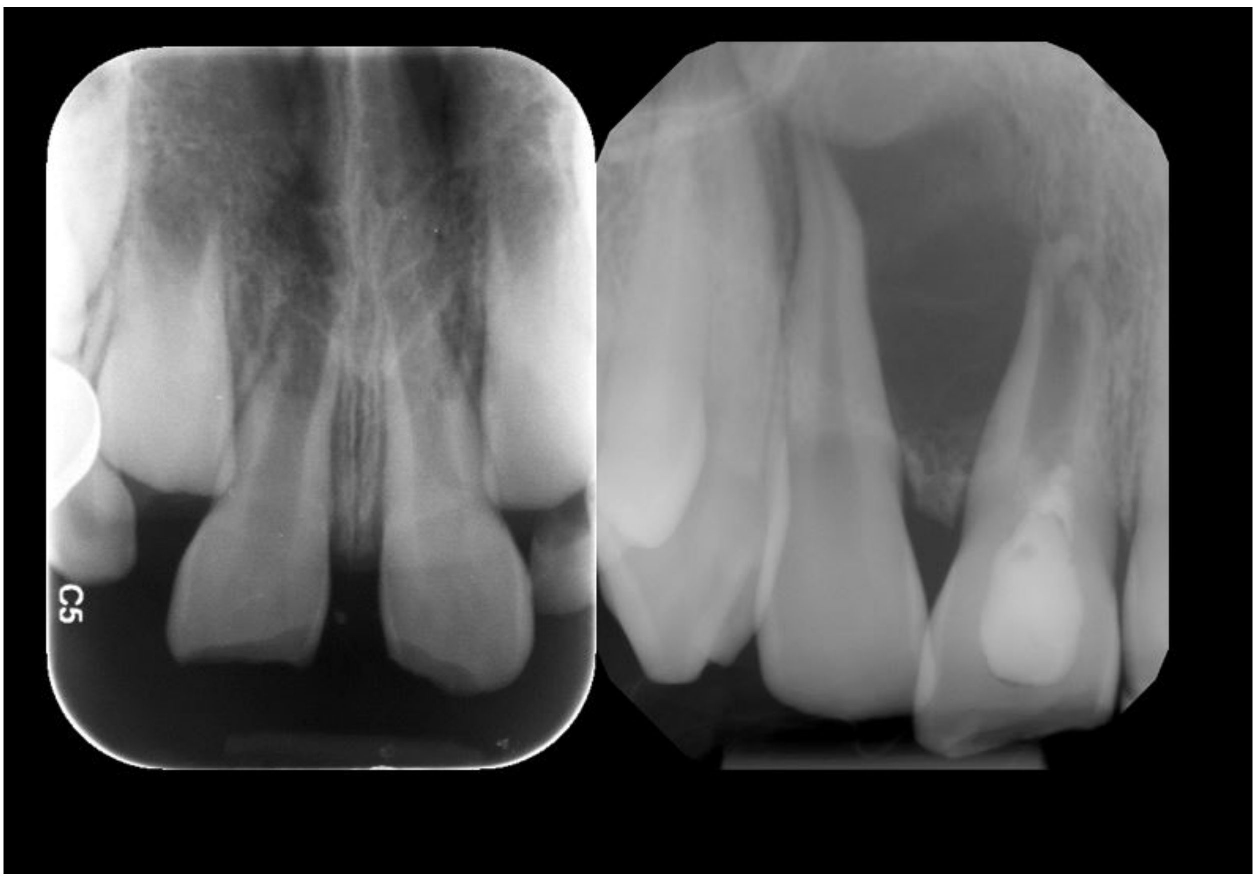

Figure 3 - Example of Failure

Table 5. Responses by Images

Tooth	Healing	Specialty ENDO	Specialty PEDO	correct
Patient 1, tooth #9	Complete Healing	1	0	
	Incomplete Healing	2	1	3
	Failure	0	2	
Patient 2, tooth #9	Complete Healing	1	1	
	Incomplete Healing	2	2	4
Patient 3, tooth #8	**Incomplete Healing**	2	2	4
	Failure	1	1	
Patient 4, tooth #9	**Incomplete Healing**	2	3	5
	Failure	1	0	
Patient 5, tooth #8	**Complete Healing**	2	1	3
	Incomplete Healing	1	2	
Patient 6, tooth #9	**Incomplete Healing**	3	3	6
Patient 7, tooth #9	**Incomplete Healing**	3	3	6
Patient 8, tooth #27	**Failure**	3	3	6
Patient 9, tooth #9	Complete Healing	0	1	
	Incomplete Healing	3	2	5
Patient 10, tooth #9	**Complete Healing**	3	1	4
	Incomplete Healing	0	1	
	Failure	0	1	
Patient 11, tooth #8	**Complete Healing**	3	3	6
Patient 12, tooth #29	**Complete Healing**	3	3	6
Patient 13, tooth #3	**Complete Healing**	2	2	4
	Incomplete Healing	1	1	
Patient 14, tooth #8	**Incomplete Healing**	3	3	6
Patient 15, tooth #9	Complete Healing	1	0	
	Incomplete Healing	2	3	5
Patient 16, tooth #20	**Complete Healing**	3	2	5
	Incomplete Healing	0	1	
Patient 17, tooth #8	Complete Healing	1	0	
	Incomplete Healing	2	3	5
Patient 18, tooth #8	**Incomplete Healing**	3	3	6
Patient 19, tooth #12	**Complete Healing**	2	3	5
	Incomplete Healing	1	0	
Patient 20, tooth #20	Incomplete Healing	2	3	
	Failure	1	0	1
Patient 21, tooth #8	Complete Healing	1	0	
	Failure	2	3	5

Discussion

While the number of patients receiving revascularization was lower than expected, some points of data are notable. Most cases were treated in children who had undergone trauma to an anterior tooth (median age of 9, central incisors 71%, and trauma 71%). Eighty-one percent of teeth treated had pulp necrosis. Five of the seven completely healed cases involved an antibiotic dressing, while one of the two cases that did not, was actually completed in one appointment, without a dressing at all (the other was treated with $Ca(OH)_2$). The one appointment case was unique in several ways: once the tooth was accessed, the chamber was empty, but vital tissue was encountered in the apical 1/3rd of the canal; additionally, the resident used chlorhexidine and did not use an intracanal medicament – both of which are not in line with AAE protocol. However, this patient had one of the more successful outcomes, both clinically and radiographically (see Figure 4).

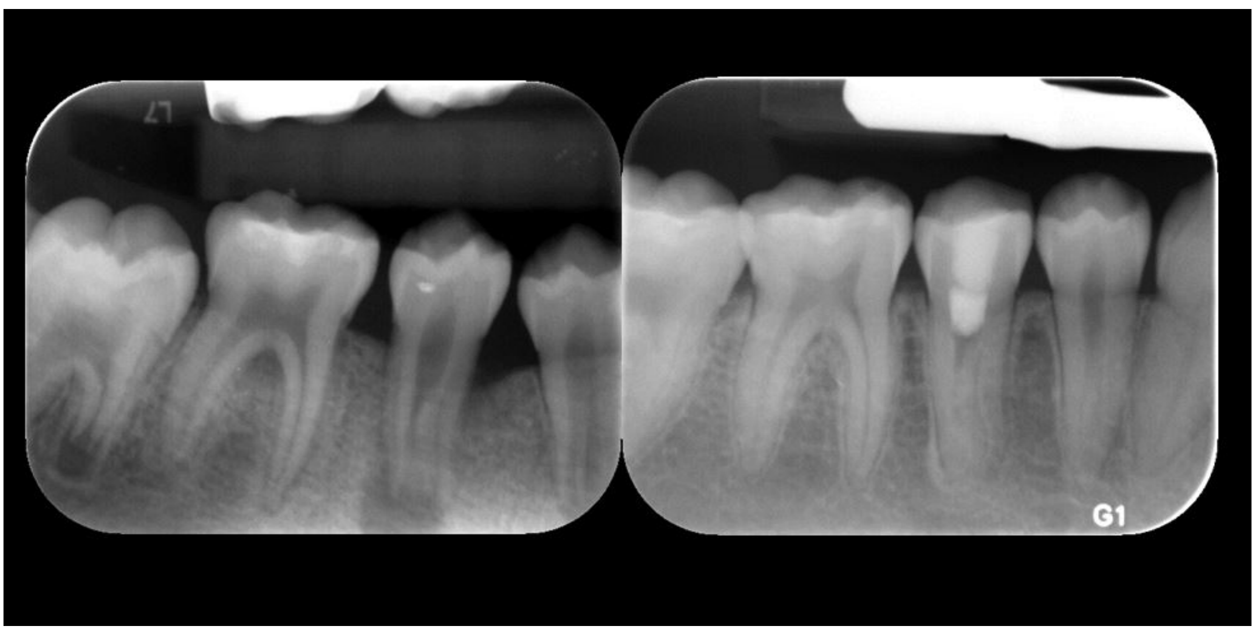

Figure 4 - Complete Healing in a revascularization case that did not follow standard AAE protocols. This case has a follow up of 40 months.

Determining success within endodontics has always been a challenge for the specialty. Does an asymptomatic lesion need to be treated? What happens to a tooth that has been treated with root canal therapy, the patient is free of symptoms, but a periapical radiolucency remains; what about success in REPs? The AAE guidelines for revascularization therapy state that patients should be free of symptoms and, radiographically, resolution of the periapical radiolucency and root thickening and lengthening should begin to occur by the 12^{th} month post treatment (11). Data from the chart review of patients at the VCU School of Dentistry yielded a wide variety of differences in the three phases of healing. Even within the distinct healing categories of complete healing, incomplete healing, and failure, differences were noted among teeth in the same category.

A total of 7 cases were classified as complete healing. Four cases (patients 11, 12, 13, and 19) within this group displayed classic patterns of uniform root thickening and lengthening – some appearing more successful than others (case 12 and 19 having more root thickening than 11 and 13). Other cases classified as completely healed appeared to have varying degrees of dentin bridging occurring at or near the apex of the tooth. In the instance of patient 16, MTA appeared to become dislodged from the main portion at the cementoenamel junction (CEJ) and travel further down the canal. This resulted in an increase in root thickening around the displaced MTA as well as an increase in root length with root closure (see Appendix C for images from the RedCap survey). Patient 5 had a similar dentin bridge formation, but with less closure of the root apex. Patient #10 also had the dentin bridge formation with apical closure, but the MTA appears to be secure below the CEJ. In this case a cone beam computed tomography scan was made and shows the dentin bridge formation and apical closure (see figure 5).

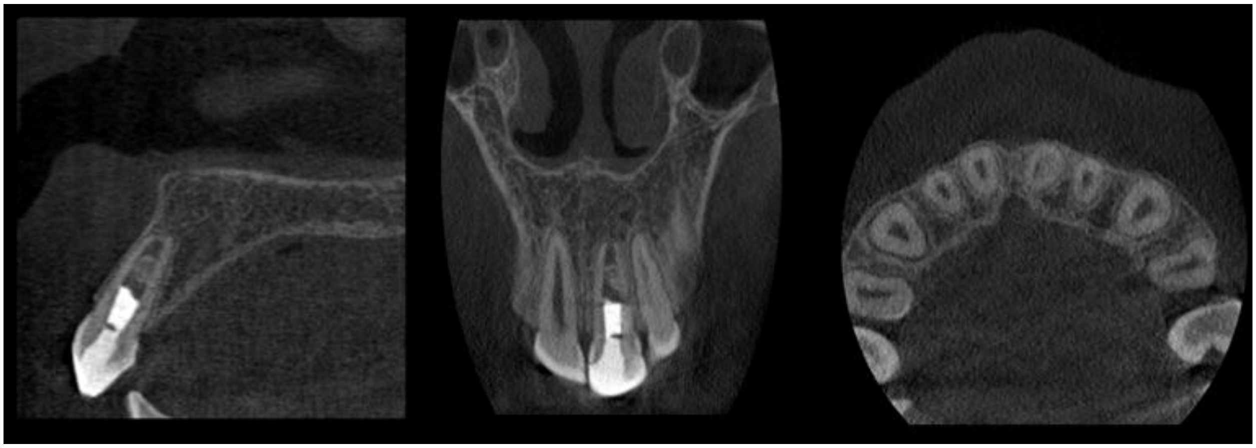

Figure 5 - CBCT of tooth #9. Note the dentin bridging in the mid-root area and the apical closure.

Interestingly, no statistical significance was noted between healing and intracanal medicament used. Bukhari noted that all cases at UPENN are treated using the same protocol using TAP, with a success rate of 75% completely healed (38). Success of revascularization therapy did not reach the same levels at VCU, with only 33.33% completely healed. The completely healed cases within this chart review showed more complete healing with the use of some type of antibiotic intracanal medicament, either DAP, TAP, or the combination of Ca(OH)2 and TAP (5 out of 7 teeth designated as completely healed). Bose et al. showed TAP to produce significantly greater increases in root thickness when compared to Ca(OH)2. Additionally, Ca(OH)2 as an intracanal medicament performed better when it was confined to the coronal portion of the root (39).

Within the incomplete healing category, varied bone healing occurred within the 9 patients available for review. In cases 1, 2, 6, 7, 15 and 18, resolution of the periapical radiolucency occurred without any root wall thickening or lengthening. In the case of patient 9 and 17, bone filled in the canal spaces while the periapical radiolucency had resolved. Case 14 had dentin bridge formation similar to those seen in vital pulp therapy, however, boney infill of the canal space is also noted.

A relationship was noted in the data between incomplete healing and trauma with a chi-square p-value = 0.0736. Nagata showed that bacteria associated with immature permanent teeth with necrotic pulps have bacteria that are resistant to both NaOCl and calcium hydroxide, including *P. endodontalis, P. micra, F nucleatum*, and most frequently *A. naeslundii*. According to his research, Nagata recommended a chlorhexidine and NaOCl irrigation mix, with the chlorhexidine modified to only be antibacterial and eliminate its deleterious effects on stem cell survival, possibly treating in only one visit with the outlined irrigant protocol, or treating in two visits with TAP or CaOH, to improve antibacterial effects in traumatized teeth (40). Trevino found, in contrast, that SCAP cell survival did not occur with the use of chlorhexidine as an intracanal medicament (14). These conflicting findings among researchers create a level of uncertainty that is only heightened when cases don't follow the AAE guidelines but appear to have great success, as exhibited by the previously mentioned case of patient 12 (see figure 4).

Vishwanat showed that in the presence of biofilm, SCAP cells tend to differentiate as osteoblastic-like cells rather than odontoblastic-like cells (41). One possible conclusion to be drawn from these findings and the response found in the incomplete healing group within this retrospective study would be that residual biofilms are responsible for the shift to a boney repair rather than a dentin repair. Sabrah showed that TAP and DAP had a residual antibacterial effect for 7 to 14 days, respectively, even at lower concentrations of 0.5 mg/ml to 1.0 mg/ml (42). Perhaps changes to the disinfection protocol should be considered in order to increase the likelihood of an outcome of complete healing.

The failed category consisted of 5 teeth with the least amount of variation, patient 3 (and 4) showed some decrease in the periapical lesion, but the patient remained symptomatic. Patient 8 had an increase in the size of the periapical radiolucency. No change was noted in the size of the periradicular radiolucency around tooth #20 in patient 20, and a draining sinus tract remained present after treatment. Patient 21 showed the widest margin of variation, with both an increase in the size of the radiolucency, but a deposition of some dentin-like material can be noted around the apex. Failures also occurred early and late, with no strong correlations to be noted within this healing category.

With regards to rating the radiographic healing, both board certified endodontists and board certified pediatric dentists were asked to read the images. Because both pediatric and endodontic residents were involved in the treatment planning of the cases included for study and are the most likely providers to follow these patients, they need to be able to determine the healing status of REPs. For 6 cases, all respondents correctly identified the proper healing category. Interestingly, a majority of respondents selected the correct healing type in all but one case, case 20. The 3 endodontists were able to correctly identify between 16 and 18 cases, while the pediatric dentists correctly identified between 15 and 17 cases. The average number of correct identifications was 16.7, or 79%, correct. Both groups appeared to perform adequately when interpreting the radiographic healing of immature permanent teeth treated with regenerative endodontic procedures.

Conclusion

Data collected from this chart review spanned a time frame of 7 years, yielding 31 cases of regenerative endodontic therapy. Considering the relatively short amount of time that endodontists have been reforming this procedure, 31 treatments seems to be an adequate starting point to establish guidelines for treatment within the VCU School of Dentistry. First, the number of cases could have been higher, had several patients not been lost after treatment planning (N-9). Additionally, 10 patients did not return for any follow up, meaning a total of 19 patients, or half of the potential recall pool, were lost to follow up.

Establishing a recall time frame early and committing residents, patients, and where applicable, patient guardians to this series of recalls, will be essential to better understand outcomes of revascularization therapy. Patients should not only be informed of the risks and benefits of REPs but should also understand that they are committed to return. A potential solution would be to establish early recall periods within relatively short periods of time, similar to those seen after a traumatic injury (like avulsion or luxation injuries). A comparable schedule of 1 month, 3 month, and 6month early recalls, followed by a 12 month and then a yearly recall for at least 1 subsequent year would be more than adequate to establish whether patient symptoms have ceased and whether radiographic healing has occurred. By creating the necessity for early recalls, more patients and their guardians will be invested in seeing how well the therapy works, and also know that their provider is committed to seeing the best possible outcome for them.

Best outcomes within the recall period included, in the majority, an antibiotic paste. An additional consideration for future treatment is a shift back to using either a dual antibiotic paste of ciprofloxacin and metronidazole, or a triple antibiotic paste that includes the addition of minocycline or a substitute like clindamycin, amoxicillin, or cefaclor, as described in the revascularization protocols (11). Currently only calcium hydroxide is being used in the VCU graduate endodontic and pediatric clinics for revascularization procedures. As has been mentioned above, calcium hydroxide needs to be placed in the coronal portion of the immature permanent tooth to be more effective, while TAP showed a higher propensity for increasing root dentin thickness (39). In a 2015 study, Rodriguez-Benitez et al. found that mTAP coupled with low concentration NaOCl and PRP yielded the highest incidence of root thickening and root length (43). A change in either the placement of calcium hydroxide or to a different medicament altogether may improve the outcomes seen at VCU to be more comparable to those at UPENN, where completely healed teeth were noted 75% of the time (38).

The results of this chart review suggest that regenerative endodontic procedures are a successful treatment option when faced with an immature permanent tooth that has a necrotic pulp. Stronger correlations were expected between choice of intracanal medicament, periapical status, etiology and healing status. Interestingly, dens evaginatus cases were 100% healed, and radiographically fared very well. One area that could have been observed in the present study was the time between initial placement of intracanal medicament and the following final appointment. Perhaps a correlation exists between the time a medicament is within the canal and healing status. Changes could be made to improve recording clinical information when performing regenerative endodontic procedures. Furthermore, changes should be considered in choice of intracanal medicament for revascularization procedures. Additionally, practitioners and patients need to be committed to the process of revascularization, including follow-up visits. While protocol in establishing follow-up time frames should be improved, with high percentages of survivability, regenerative endodontic procedures continue to be a treatment option for the immature permanent tooth with a necrotic pulp.

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Appendices

Appendix A. AAE Regenerative Endodontic Procedure Guidelines

AAE Clinical Considerations for a Regenerative Procedure
Revised 6-8-16

These considerations should be seen as one possible source of information and, given the rapid evolving nature of this field, clinicians should also actively review new findings elsewhere as they become available.

Case Selection:

- Tooth with necrotic pulp and an immature apex.
- Pulp space not needed for post/core, final restoration.
- Compliant patient/parent.
- Patients not allergic to medicaments and antibiotics necessary to complete procedure (ASA 1 or 2).

Informed Consent

- Two (or more) appointments.
- Use of antimicrobial(s).
- Possible adverse effects: staining of crown/root, lack of response to treatment, pain/infection.
- Alternatives: MTA apexification, no treatment, extraction (when deemed non-salvageable).
- Permission to enter information into AAE database (optional).

First Appointment

- Local anesthesia, dental dam isolation and access.
- Copious, gentle irrigation with 20ml NaOCl using an irrigation system that minimizes the possibility of extrusion of irrigants into the periapical space (e.g., needle with closed end and side-vents, or EndoVac™). Lower concentrations of NaOCl are advised [1.5% NaOCl (20mL/canal, 5 min) and then irrigated with saline or EDTA (20 mL/canal, 5 min), with irrigating needle positioned about 1 mm from root end, to minimize cytotoxicity to stem cells in the apical tissues.
- Dry canals with paper points.
- Place calcium hydroxide or low concentration of triple antibiotic paste. If the triple antibiotic paste is used: 1) consider sealing pulp chamber with a dentin bonding agent [to minimize risk of staining] and 2) mix 1:1:1 ciprofloxacin: metronidazole: minocycline to a final concentration of 0.1-1.0 mg/ml. Triple antibiotic paste has been associated with tooth discoloration. Double antibiotic paste without minocycline paste or substitution of minocycline for other antibiotic (e.g., clindamycin; amoxicillin; cefaclor) is another possible alternative as root canal disinfectant.
- Deliver into canal system via syringe
- If triple antibiotic paste is used, ensure that it remains below CEJ (minimize crown staining).

- Seal with 3-4mm of a temporary restorative material such as Cavit™, IRM™, glass-ionomer or another temporary material. Dismiss patient for 1-4 weeks.

Second Appointment (1-4 weeks after 1st visit)

- Assess response to initial treatment. If there are signs/symptoms of persistent infection, consider additional treatment time with antimicrobial, or alternative antimicrobial.
- Anesthesia with 3% mepivacaine without vasoconstrictor, dental dam isolation.
- Copious, gentle irrigation with 20ml of 17% EDTA.
- Dry with paper points.
- Create bleeding into canal system by over-instrumenting (endo file, endo explorer) (induce by rotating a pre-curved K-file at 2 mm past the apical foramen with the goal of having the entire canal filled with blood to the level of the cemento–enamel junction). An alternative to creating of a blood clot is the use of platelet-rich plasma (PRP), platelet rich fibrin (PRF) or autologous fibrin matrix (AFM).
- Stop bleeding at a level that allows for 3-4 mm of restorative material.
  - Place a resorbable matrix such as CollaPlug™, Collacote™, CollaTape™ over the blood clot if necessary and white MTA as capping material.
- A 3–4 mm layer of glass ionomer (e.g. Fuji IX™, GC America, Alsip, IL) is flowed gently over the capping material and light-cured for 40 s. MTA has been associated with discoloration. Alternatives to MTA (such as bioceramics or tricalcium silicate cements [e.g., Biodentine®, Septodont, Lancasted, PA, USA]) should be considered in teeth where there is an esthetic concern.
  - Anterior and Premolar teeth - Consider use of Collatape/Collaplug and restoring with 3mm of a nonstaining restorative material followed by bonding a filled composite to the beveled enamel margin.
  - Molar teeth or teeth with PFM crown - Consider use of Collatape/Collaplug and restoring with 3mm of MTA, followed by RMGI, composite or alloy.

Follow-up

- Clinical and Radiographic exam
  - No pain, soft tissue swelling or sinus tract (often observed between first and second appointments).
  - Resolution of apical radiolucency (often observed 6-12 months after treatment)
  - Increased width of root walls (this is generally observed before apparent increase in root length and often occurs 12-24 months after treatment).
  - Increased root length.
  - Positive Pulp vitality test response
- The degree of success of Regenerative Endodontic Procedures is largely measured by the extent to which it is possible to attain primary, secondary, and tertiary goals:
  - Primary goal: The elimination of symptoms and the evidence of bony healing.
  - Secondary goal: Increased root wall thickness and/or increased root length (desirable, but perhaps not essential)
  - Tertiary goal: Positive response to vitality testing (which if achieved, could indicate a more organized vital pulp tissue)

Appendix B. Cases used in the study

ID	Gender	Age	Tooth	Etiology	Pulpal Diagnosis	Periapical Diagnosis	Intracanal Medicament	Follow-up (months)	Healing Status (Radiograph)	Healing Status (Chart)	Survey #
2	M	8	9	Trauma	Pulp Necrosis	Asymptomatic Apical Periodontitis	Ca(OH)2	12	Incomplete	Incomplete	Pt 1
3	M	6	9	Trauma	Asymptomatic Irreversible Pulpitis	Normal Apical Tissue	none	2	Incomplete	Incomplete	Pt 2
6	M	6	8	Trauma	Pulp Necrosis	Asymptomatic Apical Periodontitis	Ca(OH)2	15	Complete	Complete	Pt 5
8	M	7	9	Trauma	Pulp Necrosis	Chronic Apical Abscess	Ca(OH)2	7	Incomplete	Incomplete	Pt 6
11	F	7	9	Trauma	Pulp Necrosis	Chronic Apical Abscess	Ca(OH)2	11	Incomplete	Incomplete	Pt 7
13	M	12	27	Unknown	Pulp Necrosis	Asymptomatic Apical Periodontitis	Ca(OH)2	7	Failure	Failure	Pt 8
17	M	10	9	Trauma	Pulp Necrosis	Symptomatic Apical Periodontitis	DAP	23	Incomplete	Incomplete	Pt 9
20	F	6	9	Trauma	Reversible Pulpitis	Normal Apical Tissue	TAP	18	Complete	Complete	Pt 10
27	M	8	8	Trauma	Symptomatic Irreversible Pulpitis	Normal Apical Tissue	TAP	9	Complete	Complete	Pt 11
31	F	10	29	Dens Evaginatus	Pulp Necrosis	Acute Apical Abscess	none	40	Complete	Complete	Pt 12
33	M	13	3	Caries	Previously Initiated	Symptomatic Apical Periodontitis	DAP	1	Complete	Complete	Pt 13
34	F	8	8	Trauma	Pulp Necrosis	Symptomatic Apical Periodontitis	DAP	35	Incomplete	Incomplete	Pt 14
36	M	16	8	Trauma	Pulp Necrosis	Acute Apical Abscess	TAP	17	Incomplete	Failure	Pt 3
37			9	Trauma	Pulp Necrosis	Acute Apical Abscess	TAP	17	Incomplete	Failure	Pt 4
43	M	14	9	Trauma	Pulp Necrosis	Asymptomatic	TAP	14	Incomplete	Incomplete	Pt 15

ID	Gender	Age	Tooth	Etiology	Pulpal Diagnosis	Periapical Diagnosis	Intracanal Medicament	Follow-up (months)	Healing Status (Radiograph)	Healing Status (Chart)	Survey #
						Apical Periodontitis					
47	M	10	20	Dens Evaginatus	Pulp Necrosis	Chronic Apical Abscess	DAP	29	Complete	Complete	Pt 16
49	M	8	8	Trauma	Pulp Necrosis	Symptomatic Apical Periodontitis	DAP	42	Incomplete	Incomplete	Pt 17
57	M	12	8	Trauma	Pulp Necrosis	Asymptomatic Apical Periodontitis	DAP	1	Incomplete	Incomplete	Pt 18
66	M	10	12	Caries	Pulp Necrosis	Chronic Apical Abscess	$Ca(OH)_2$, TAP	36	Complete	Complete	Pt 19
75	M	13	20	Caries	Pulp Necrosis	Asymptomatic Apical Periodontitis	$Ca(OH)_2$	4	Failure	Failure	Pt 20
79	M	6	8	Trauma	Pulp Necrosis	Chronic Apical Abscess	TAP	55	Failure	Failure	Pt 21

Appendix C. REDCAP survey

Evaluation of Healing and Success

First, we ask you look at 5 calibration cases and verify that you agree with the intended evaluation.

Then there are 21 cases to evaluate.

Please complete the survey below.

Thank you!

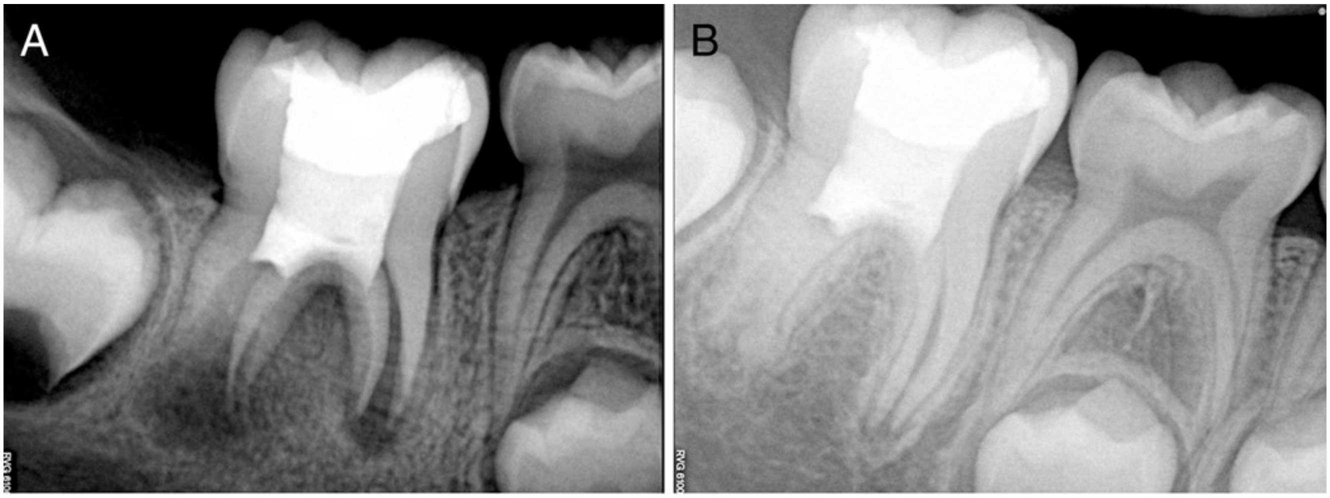
Response was added on 03/09/2018 11:31am.

Rater's name

- ◯ Archer
- ◯ Brecher
- ◯ Dahlke
- ◯ Myers
- ◯ Schachman
- ⊗ Sedwick
- ◯ Spatafore
- ◯ Wunsch

Calibration Patient 1

This case illustrates complete healing.



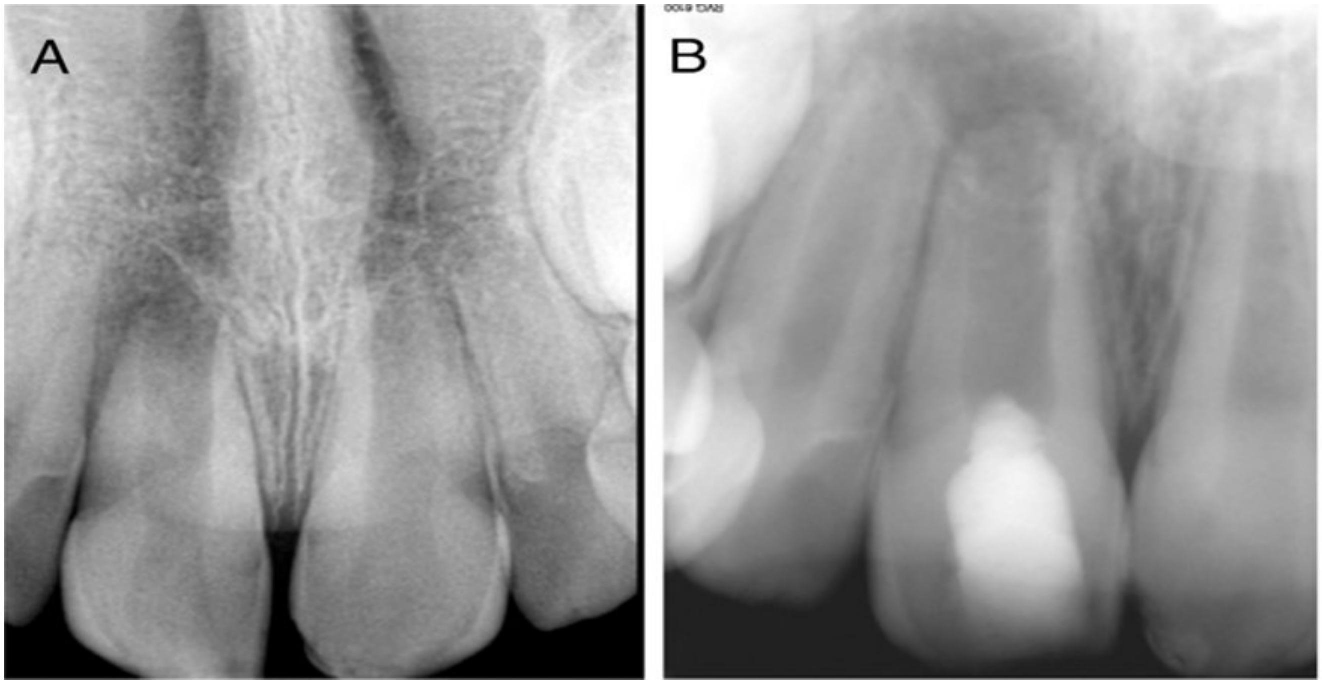
Calibration Patient 1, tooth #30
Please choose your assessment.

⊗ Complete Healing
◯ Incomplete Healing
◯ Failure

Yes. That's correct.
Press NEXT PAGE to go to the next image.

Calibration Patient 2

This case illustrates treatment failure.



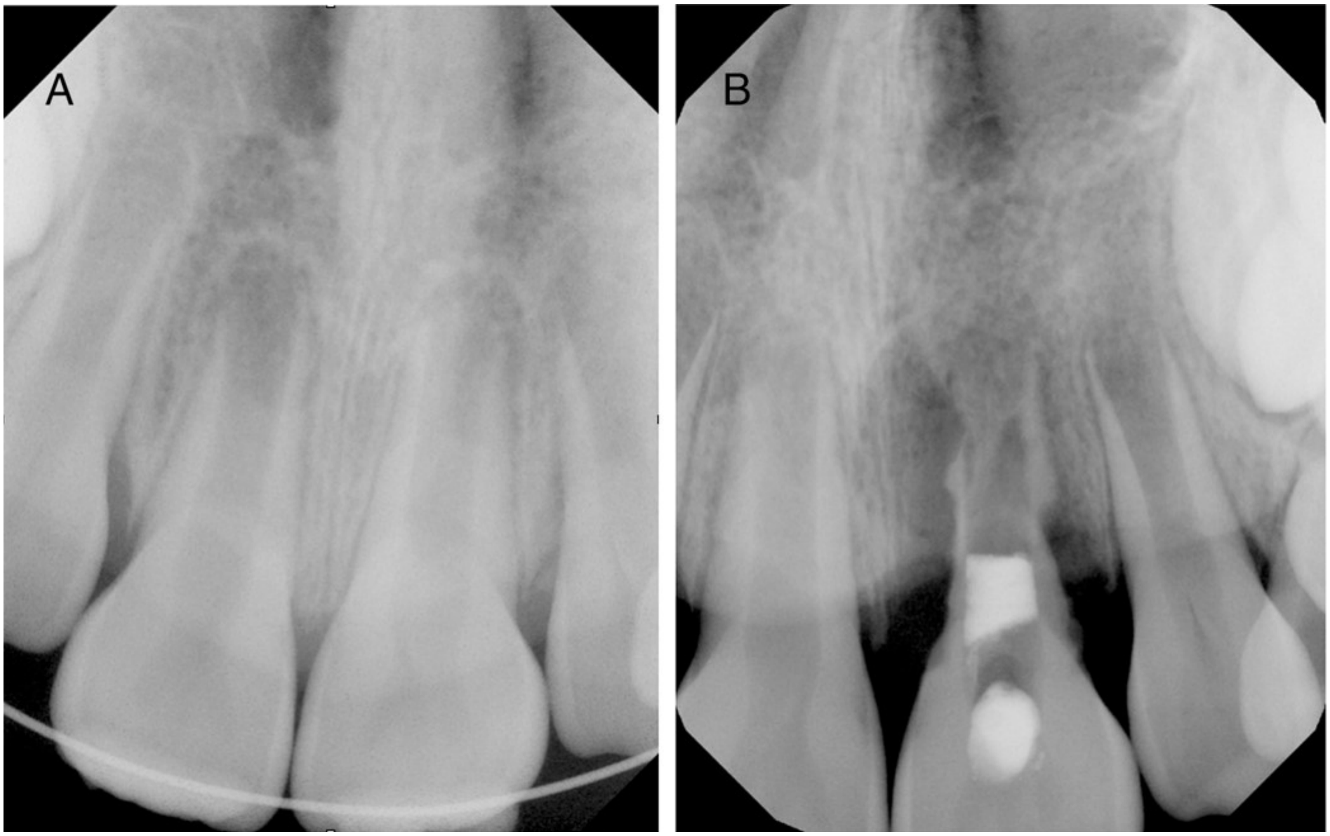
Calibration Patient 2, tooth #8

◯ Complete Healing
◯ Incomplete Healing
⊗ Failure

Yes. That's correct.
Press NEXT PAGE to go to the next image.

Calibration Patient 3

This case illustrates failure



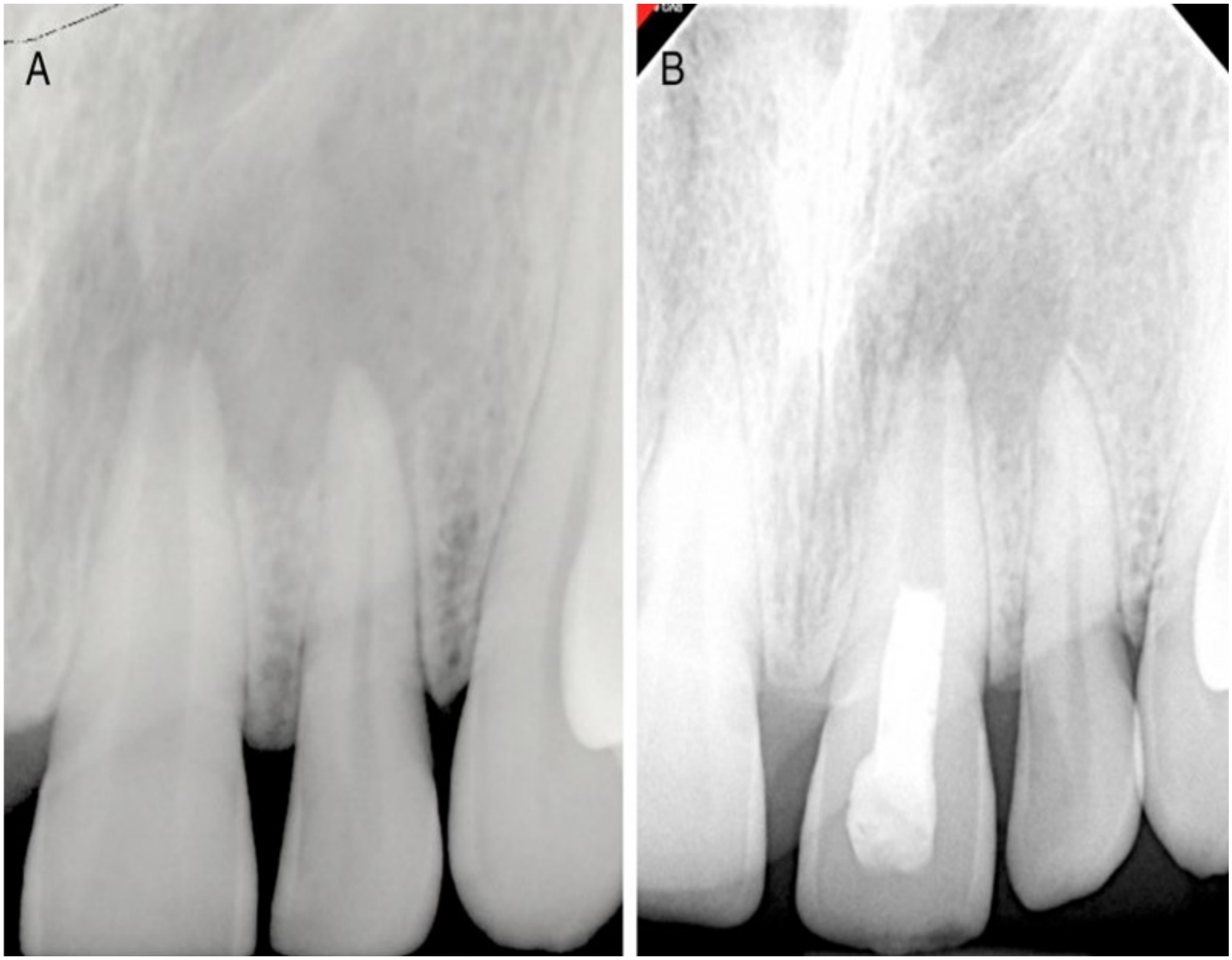
Calibration Patient 3, tooth #9

◯ Complete Healing
◯ Incomplete Healing
⊗ Failure

Yes. That's correct.
Press NEXT PAGE to go to the next image.

Calibration Patient 4

This case illustrates incomplete healing.



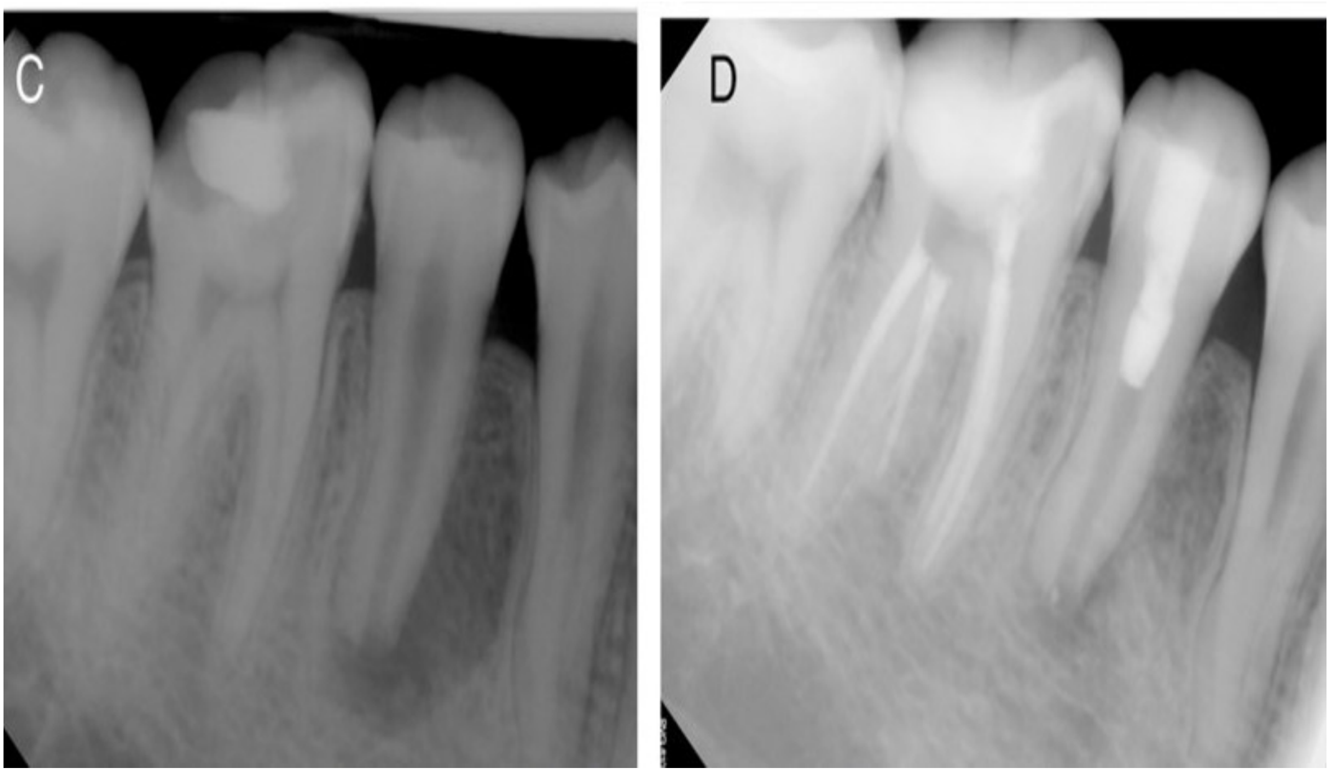
Calibration Patient 4, tooth #9

◯ Complete Healing
⊗ Incomplete Healing
◯ Failure

Yes. That's correct.
Press NEXT PAGE to go to the next image.

Calibration Patient 5

This case illustrates incomplete healing.



Calibration Patient 5, tooth #29

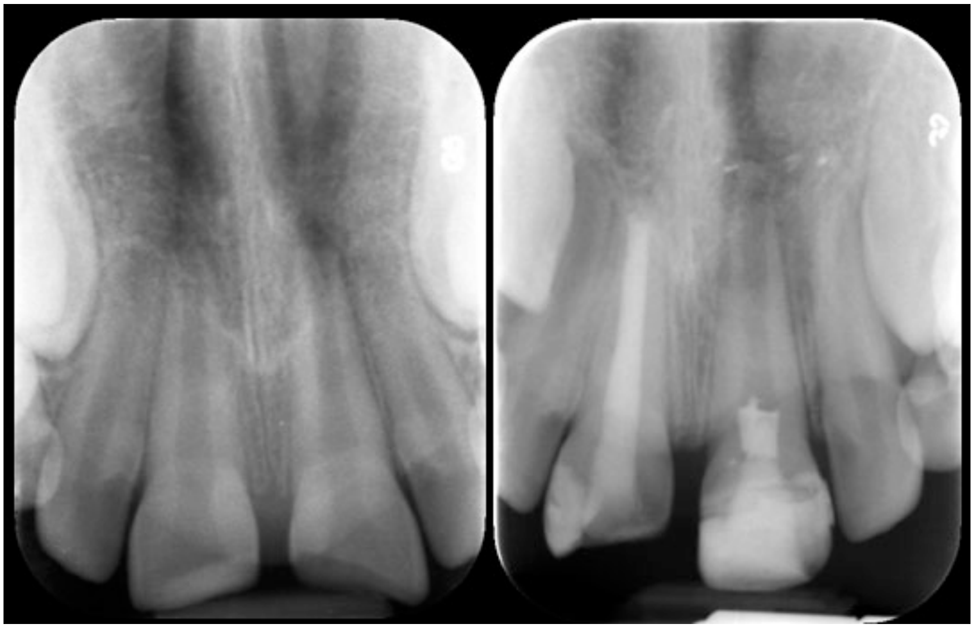
◯ Complete Healing
⊗ Incomplete Healing
◯ Failure

Yes. That's correct.
Press NEXT PAGE to go to the next image.

Your evaluation of cases:

Patient 1

Periapicals

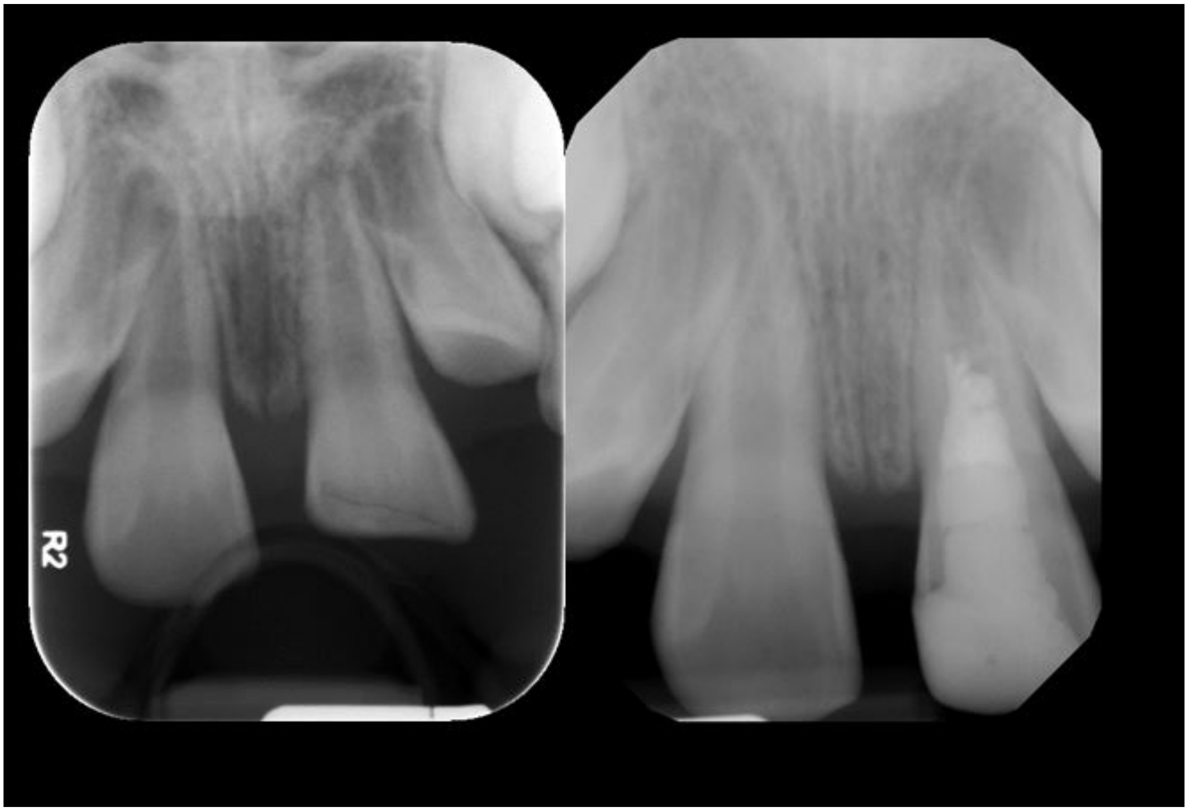


Patient 1, tooth #9

◯ Complete Healing
⊗ Incomplete Healing
◯ Failure

Patient 2

Periapicals

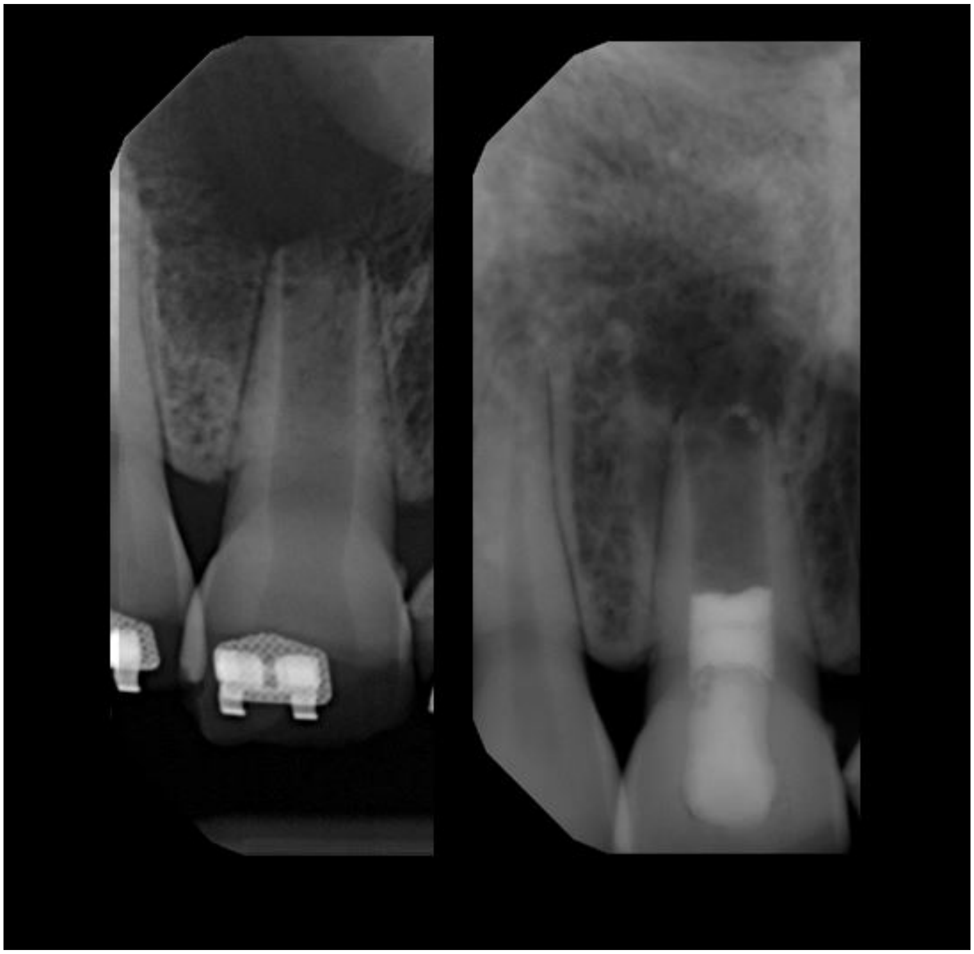


Patient 2, tooth #9

◯ Complete Healing
⊗ Incomplete Healing
◯ Failure

Patient 3

Periapicals

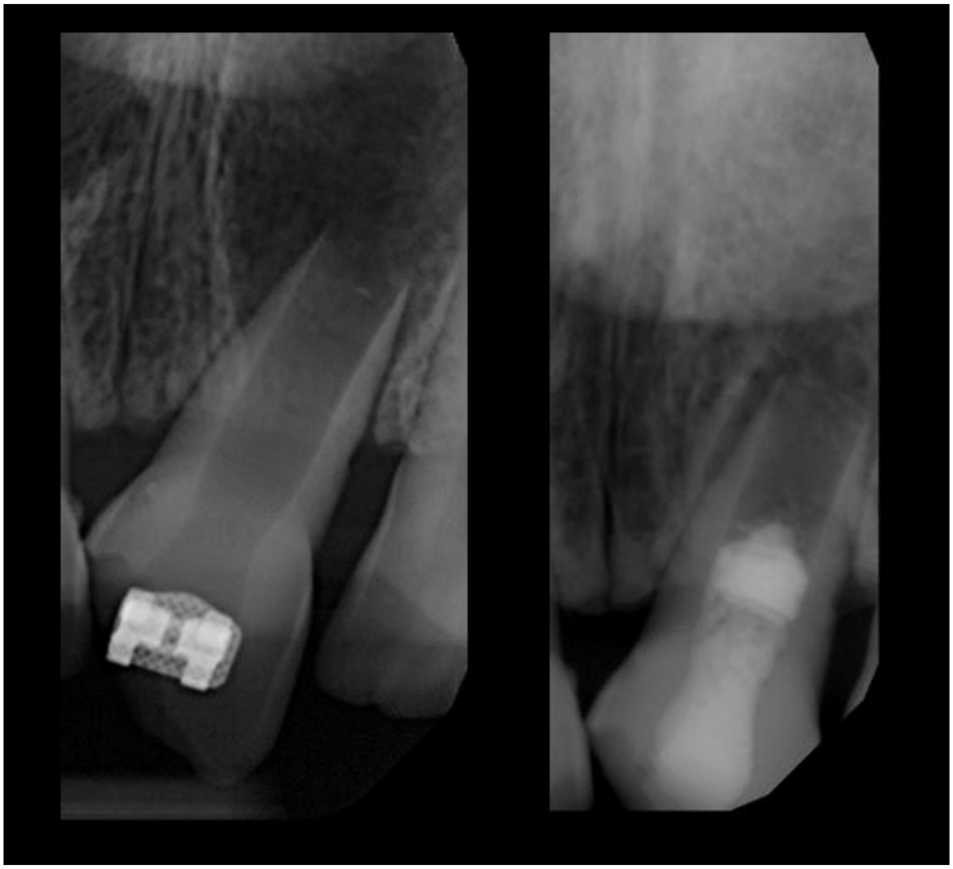


Patient 3, tooth #8

◯ Complete Healing
⊗ Incomplete Healing
◯ Failure

Patient 4

Periapicals

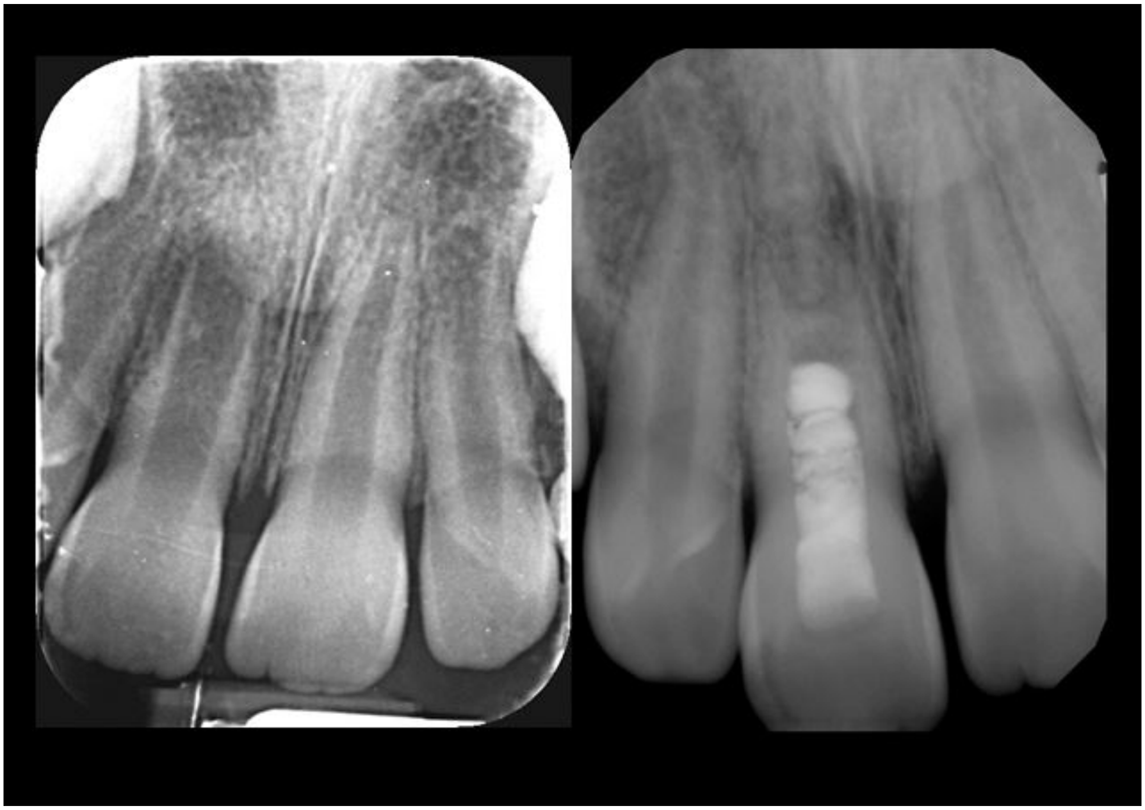


Patient 4, tooth #9

◯ Complete Healing
⊗ Incomplete Healing
◯ Failure

Patient 5

Periapicals

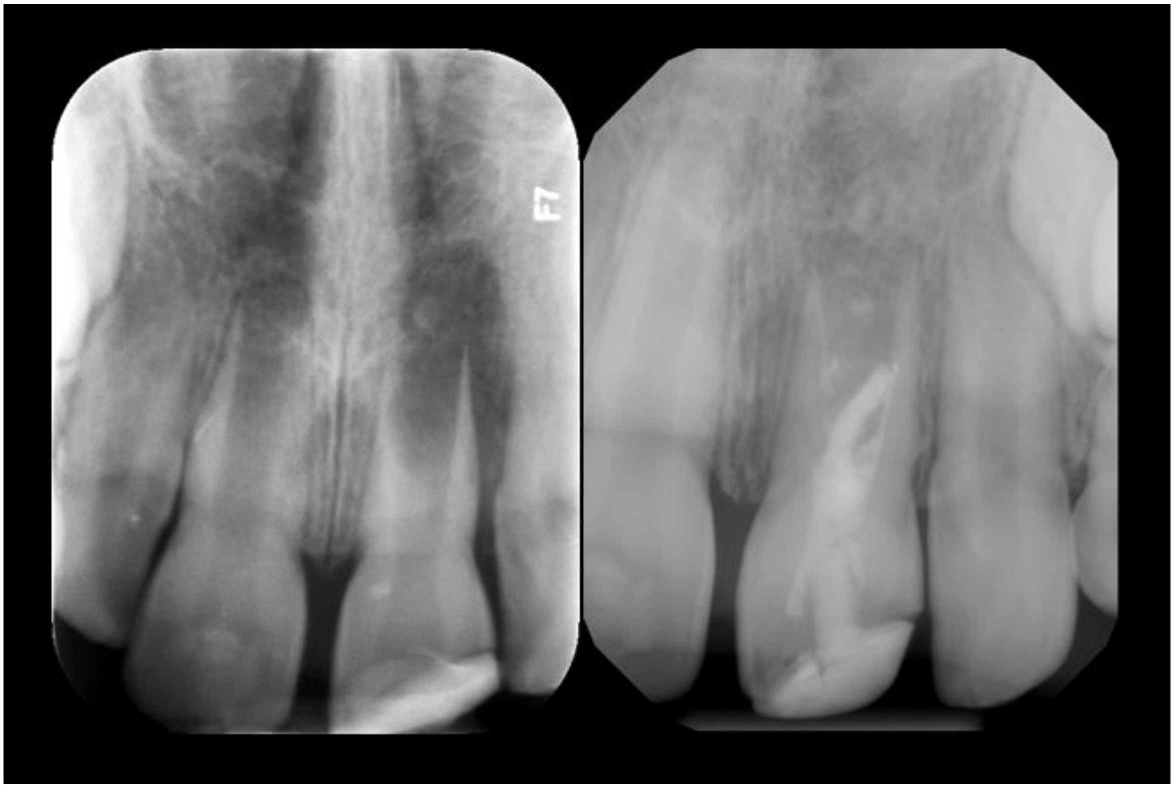


Patient 5, tooth #8

⊗ Complete Healing
◯ Incomplete Healing
◯ Failure

Patient 6

Periapicals

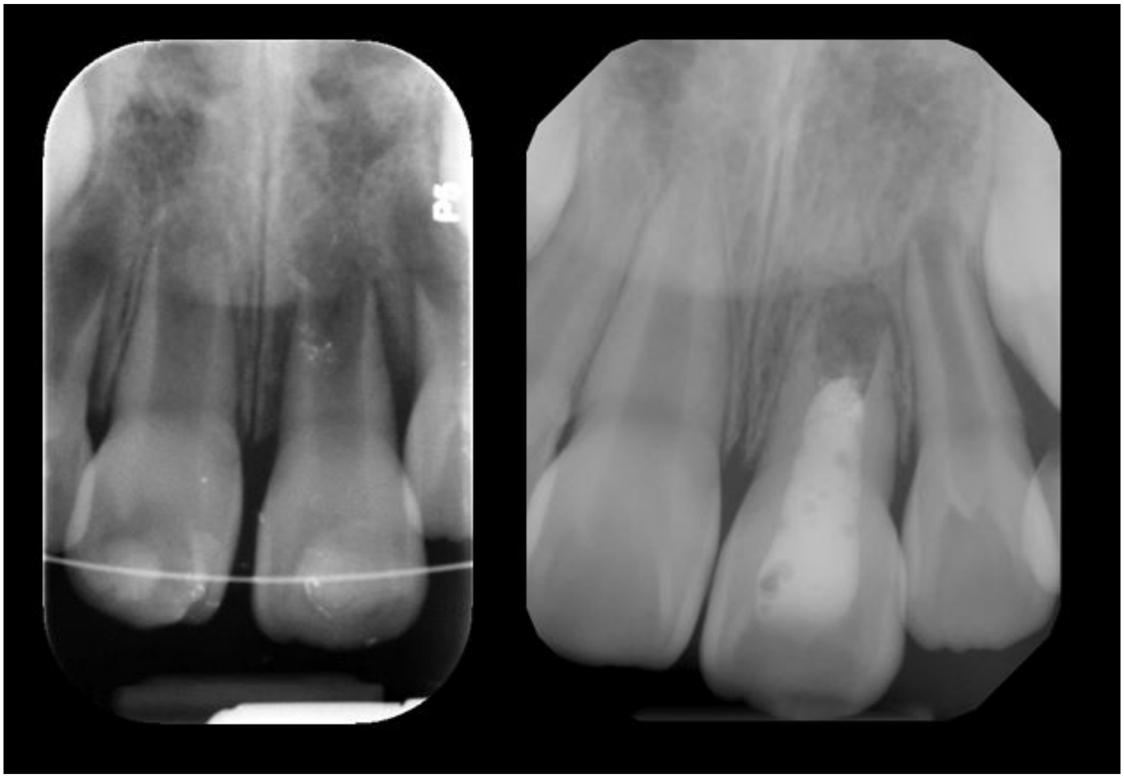


Patient 6, tooth #9

◯ Complete Healing
⊗ Incomplete Healing
◯ Failure

Patient 7

Periapicals

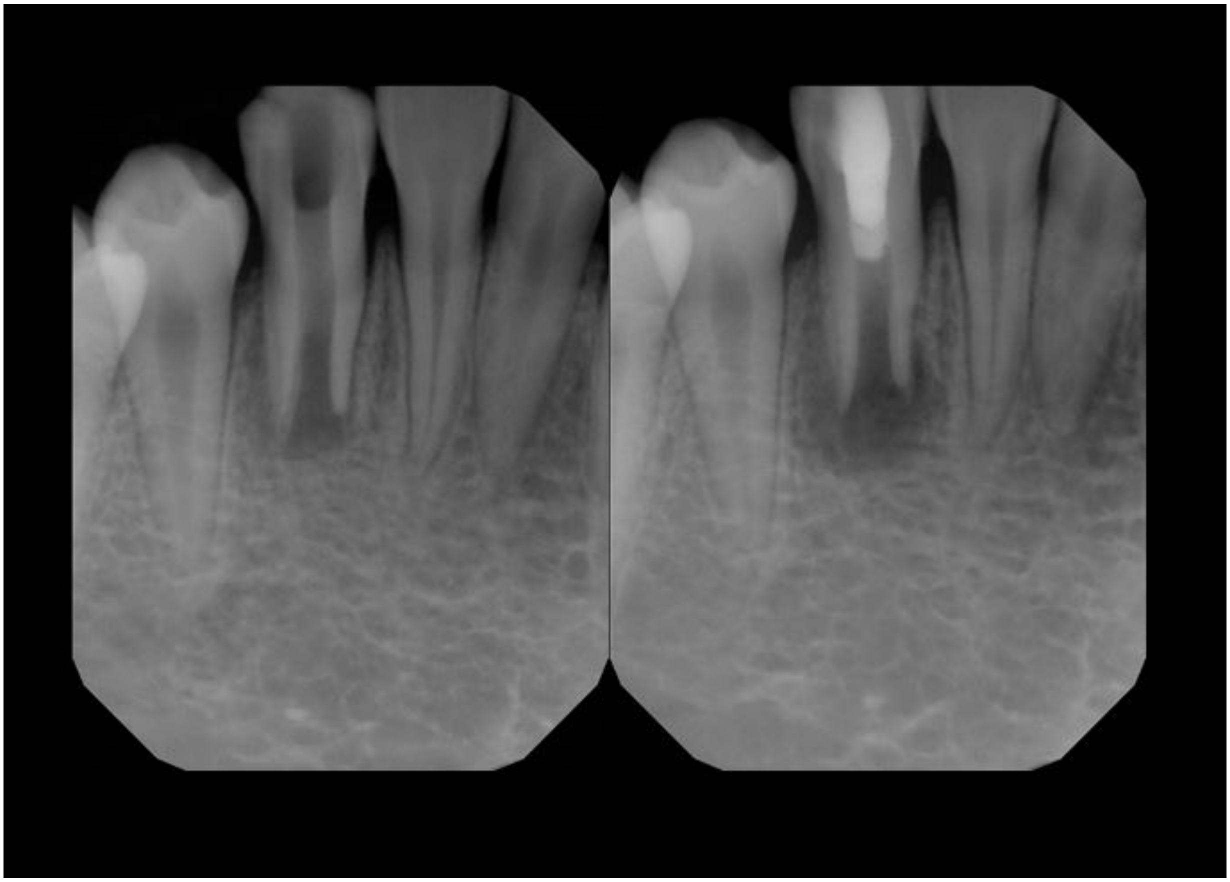


Patient 7, tooth #9

◯ Complete Healing
⨂ Incomplete Healing
◯ Failure

Patient 8

Periapicals

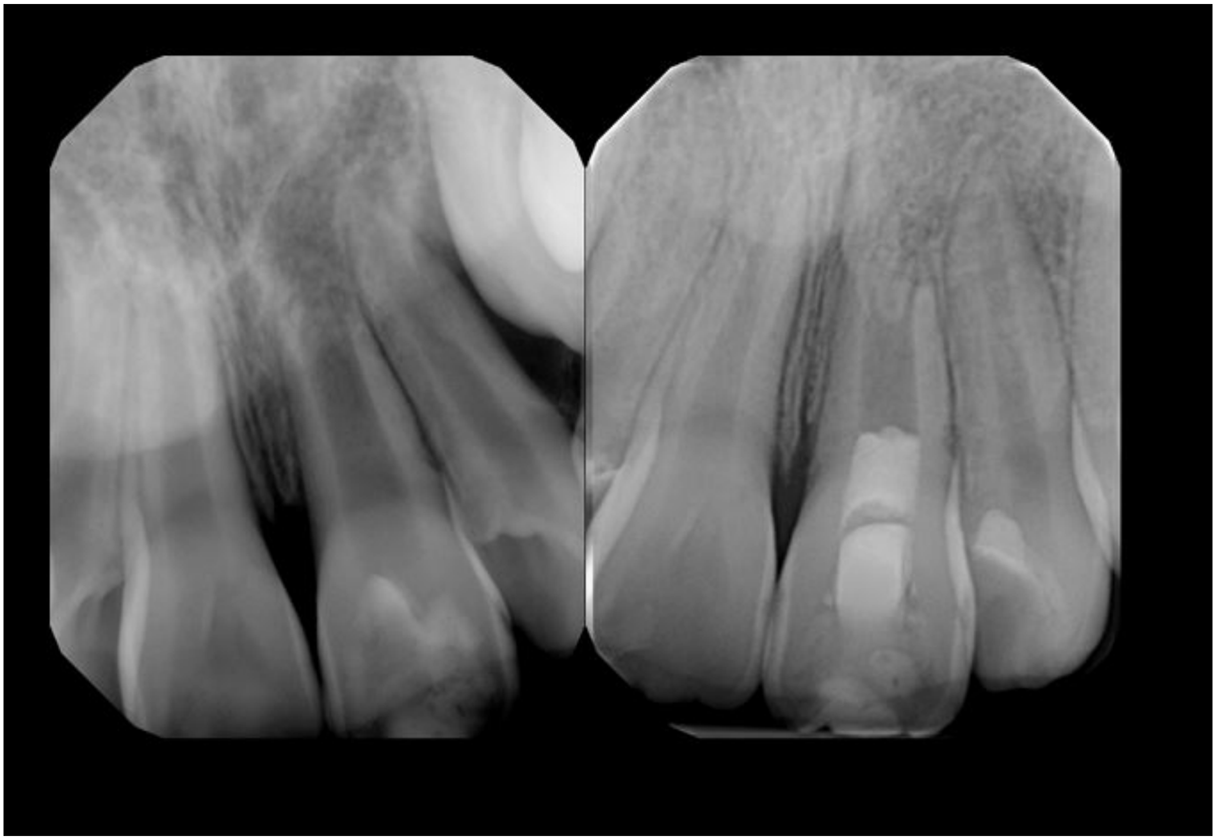


Patient 8, tooth #27

◯ Complete Healing
◯ Incomplete Healing
⊗ Failure

Patient 9

Periapicals

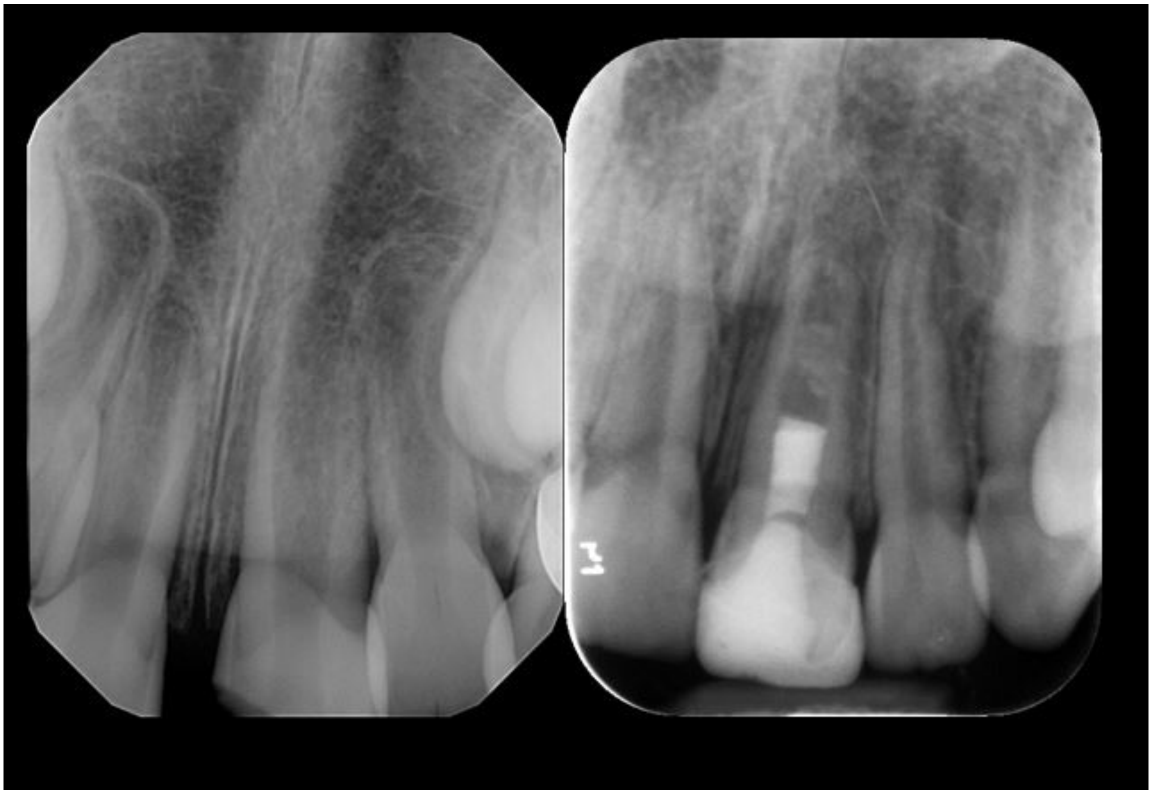


Patient 9, tooth #9

◯ Complete Healing
⊗ Incomplete Healing
◯ Failure

Patient 10

Periapicals

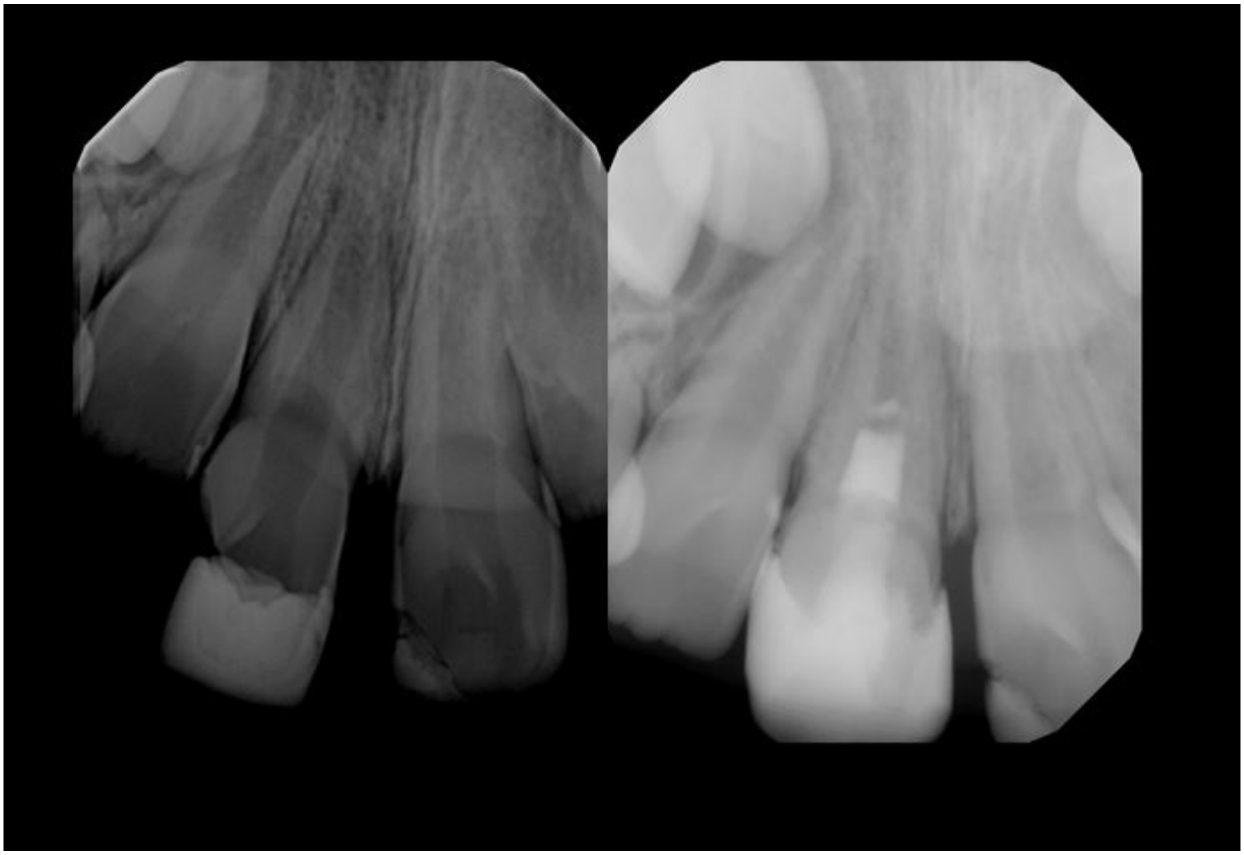


Patient 10, tooth #9

⊗ Complete Healing
◯ Incomplete Healing
◯ Failure

Patient 11

Periapicals

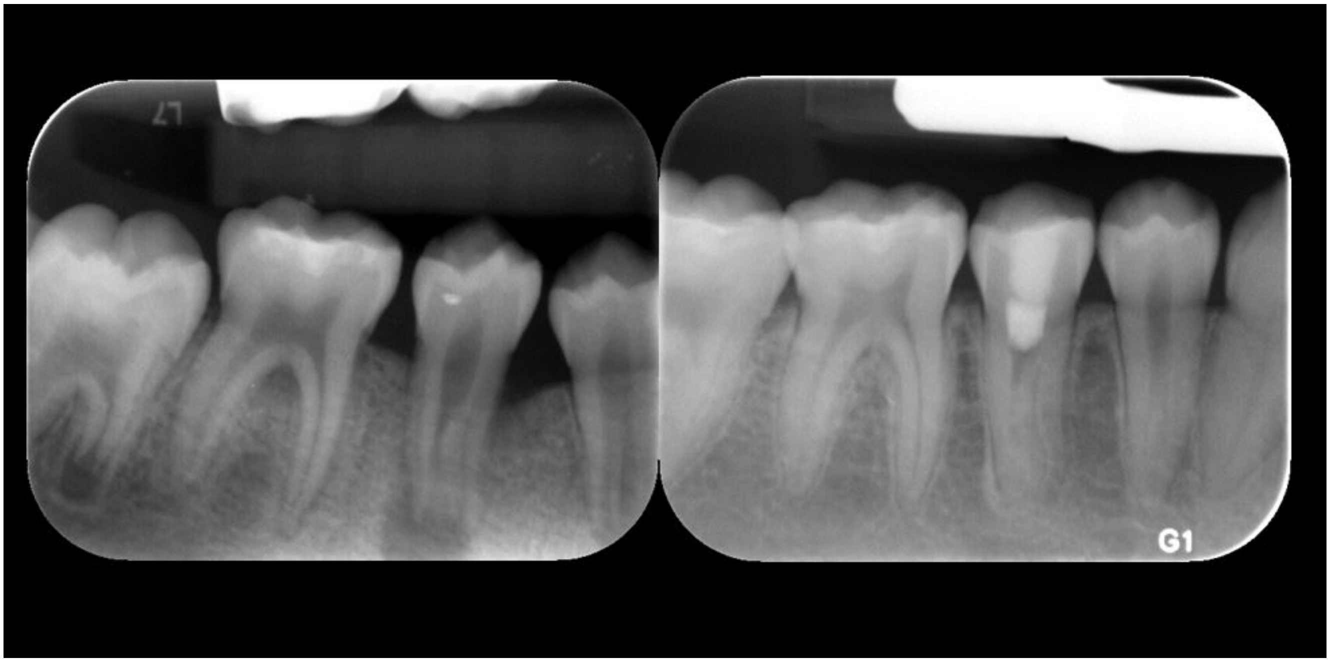


Patient 11, tooth #8

◯ Complete Healing
⨂ Incomplete Healing
◯ Failure

Patient 12

Periapicals

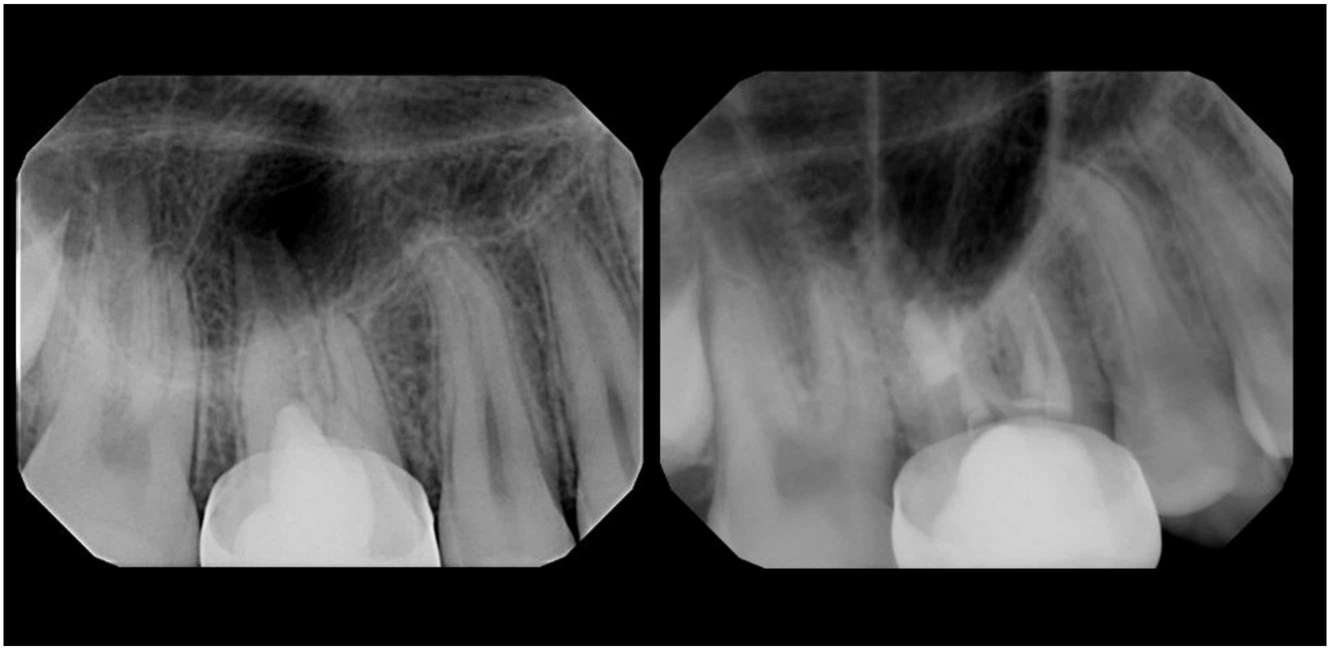


Patient 12, tooth #29

⊗ Complete Healing
◯ Incomplete Healing
◯ Failure

Patient 13

Periapicals

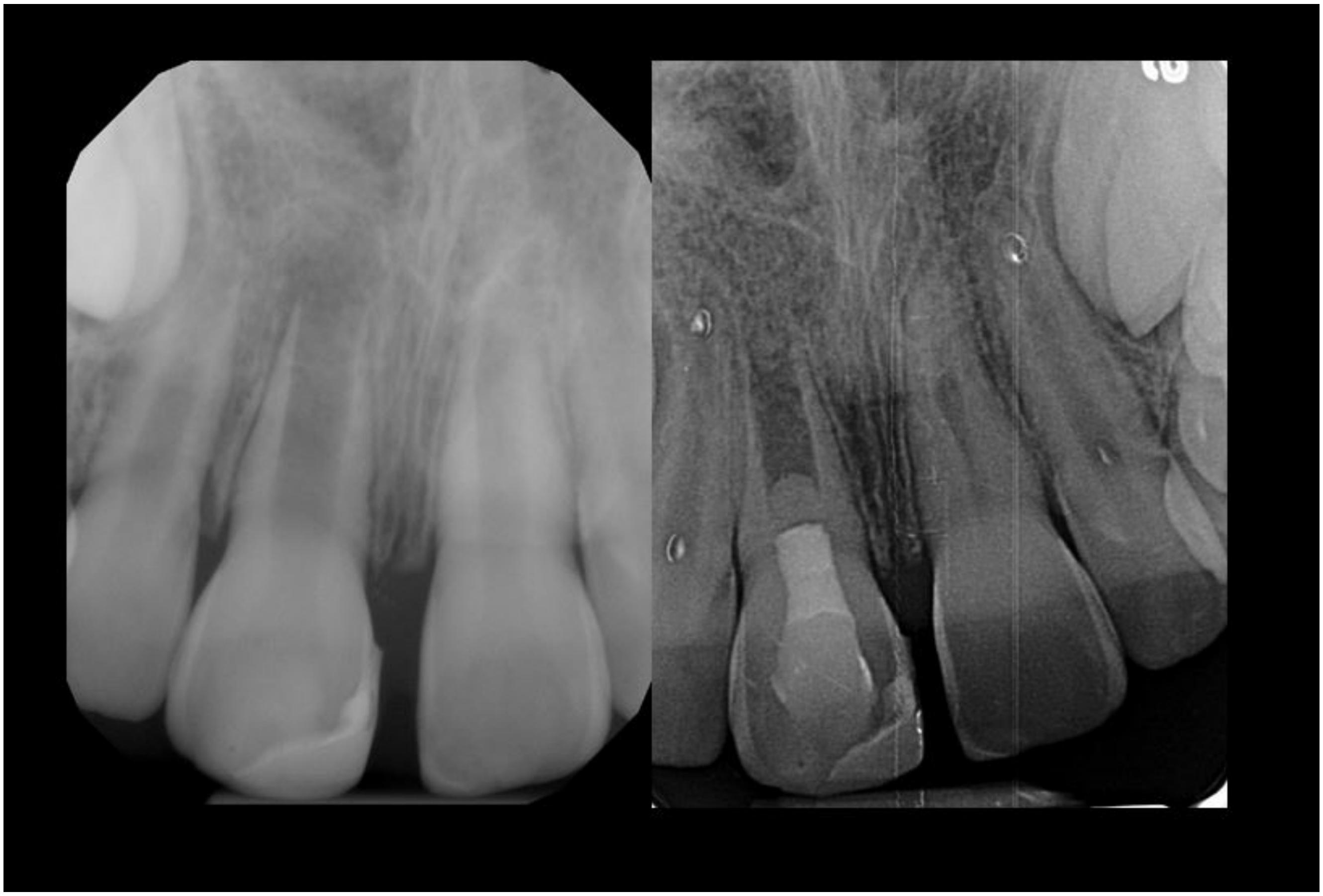


Patient 13, tooth #3

◯ Complete Healing
⊗ Incomplete Healing
◯ Failure

Patient 14

Periapicals

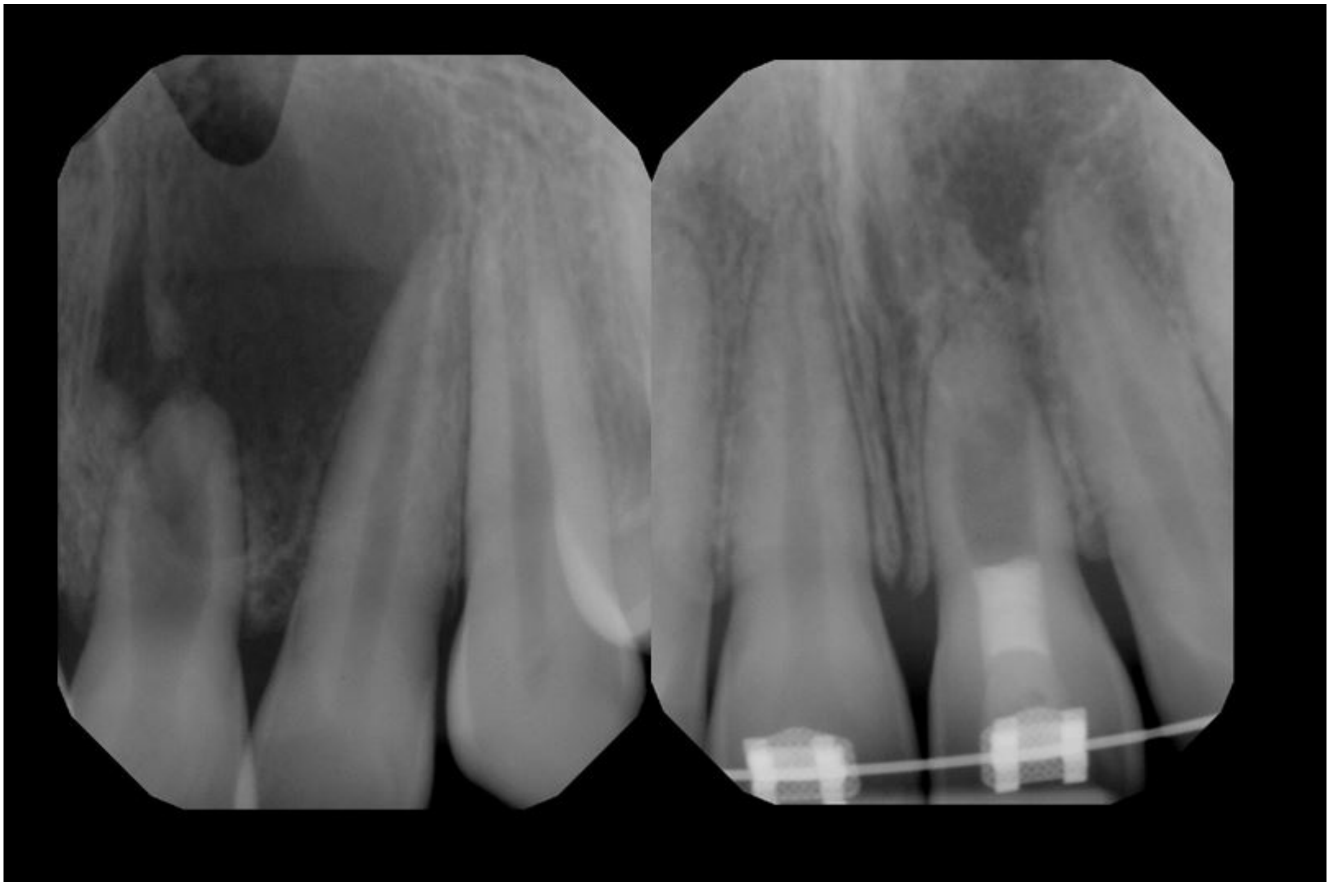


Patient 14, tooth #8

◯ Complete Healing
⨂ Incomplete Healing
◯ Failure

Patient 15

Periapicals

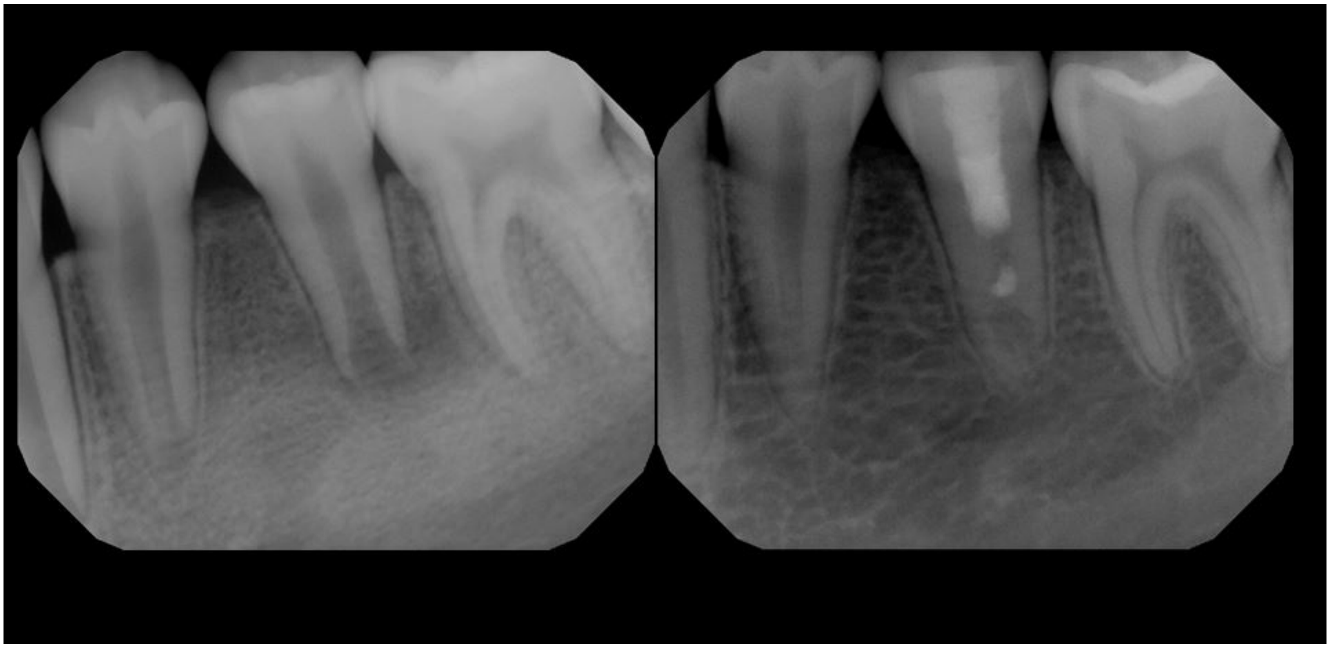


Patient 15, tooth #9

◯ Complete Healing
⨂ Incomplete Healing
◯ Failure

Patient 16

Periapicals

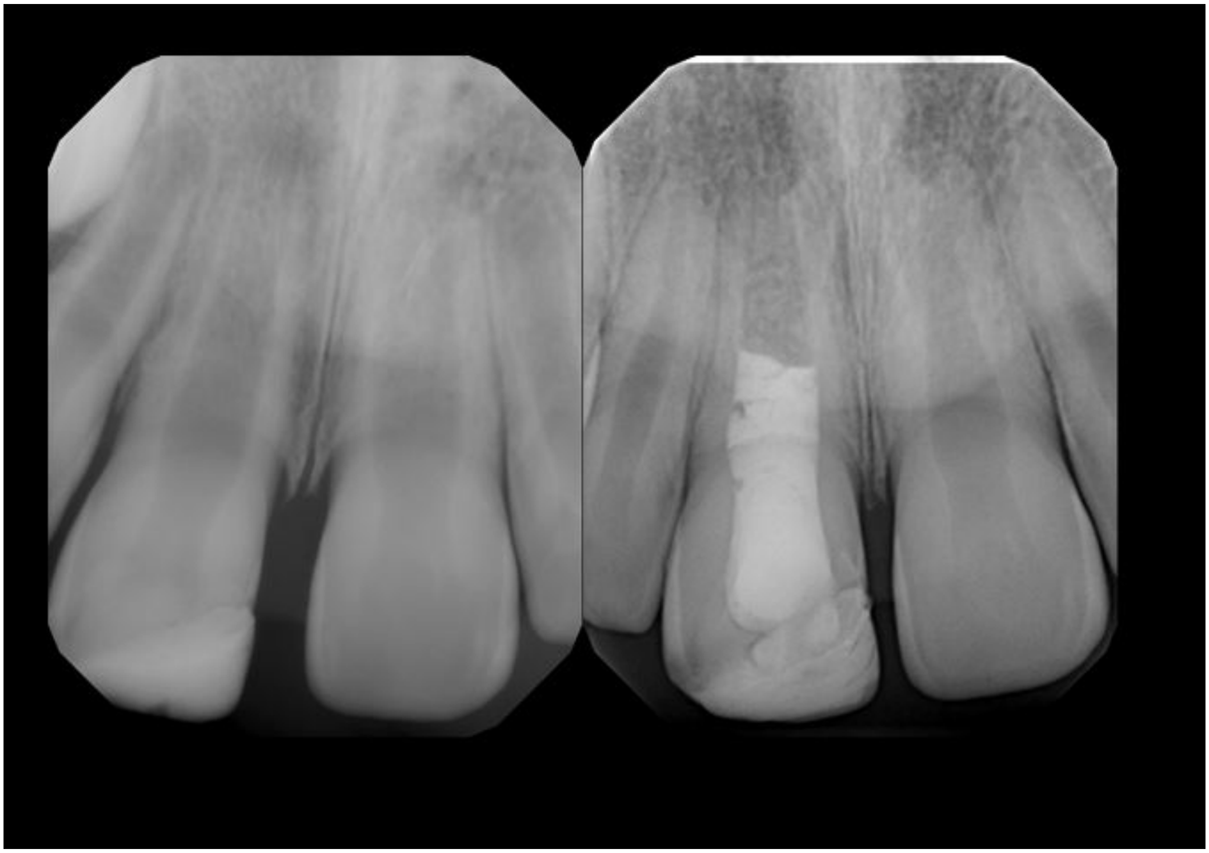


Patient 16, tooth #20

⊗ Complete Healing
◯ Incomplete Healing
◯ Failure

Patient 17

Periapicals

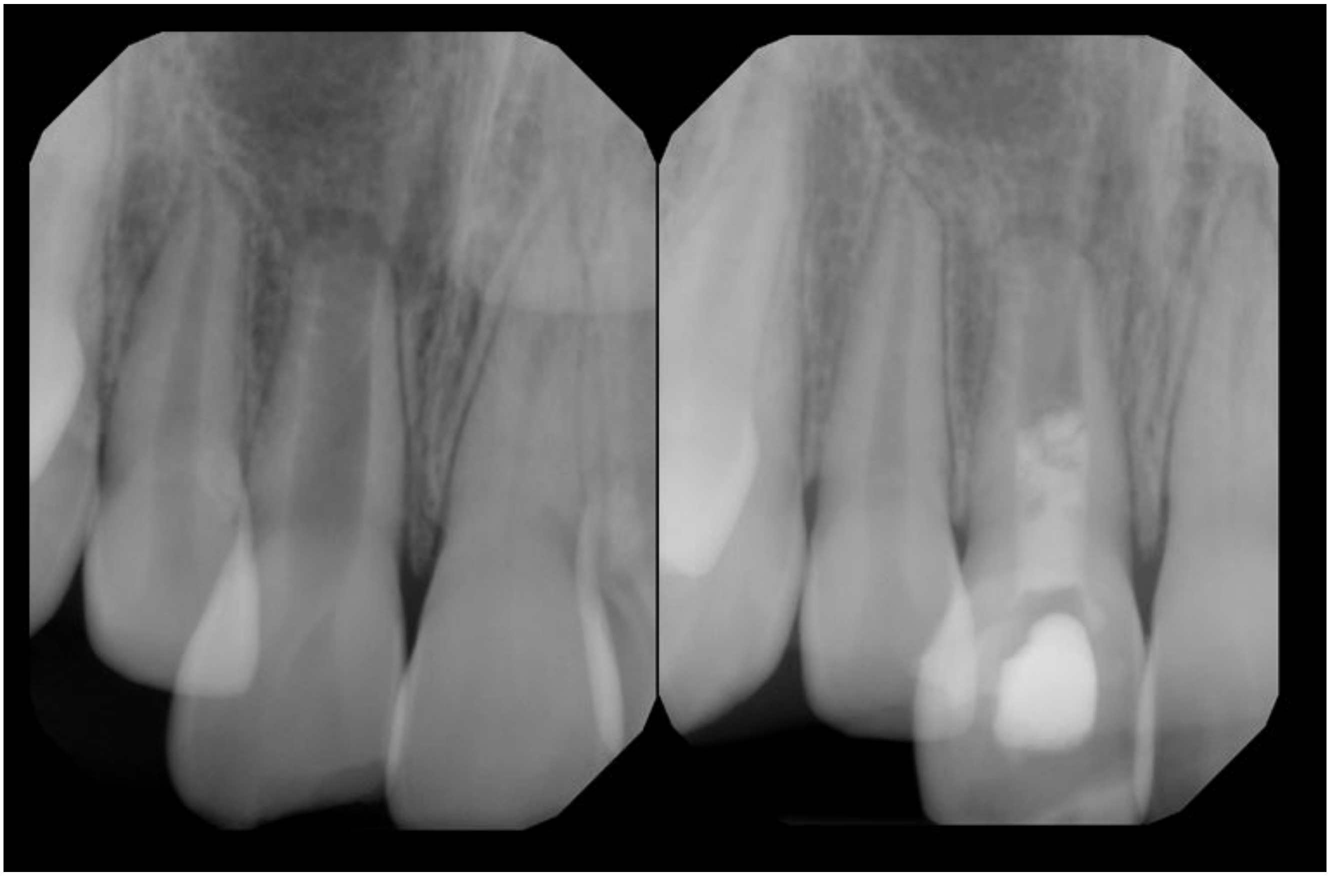


Patient 17, tooth #8

◯ Complete Healing
⊗ Incomplete Healing
◯ Failure

Patient 18

Periapicals

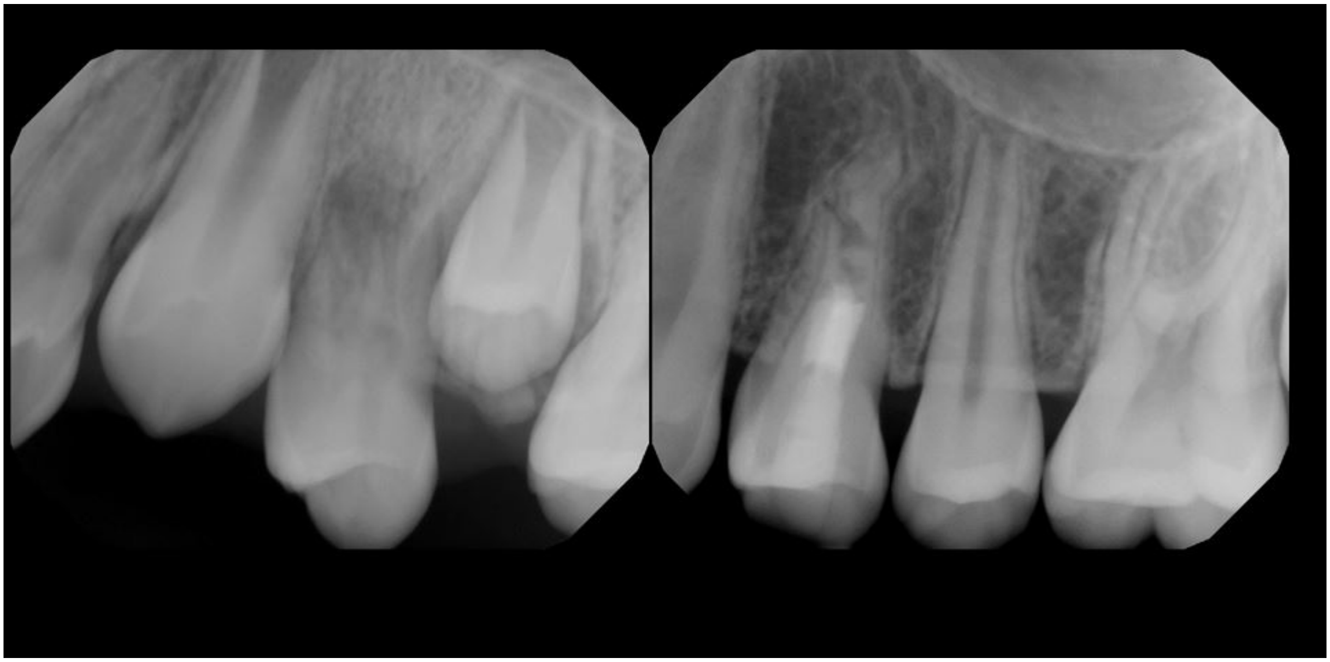


Patient 18, tooth #8

◯ Complete Healing
⊗ Incomplete Healing
◯ Failure

Patient 19

Periapicals

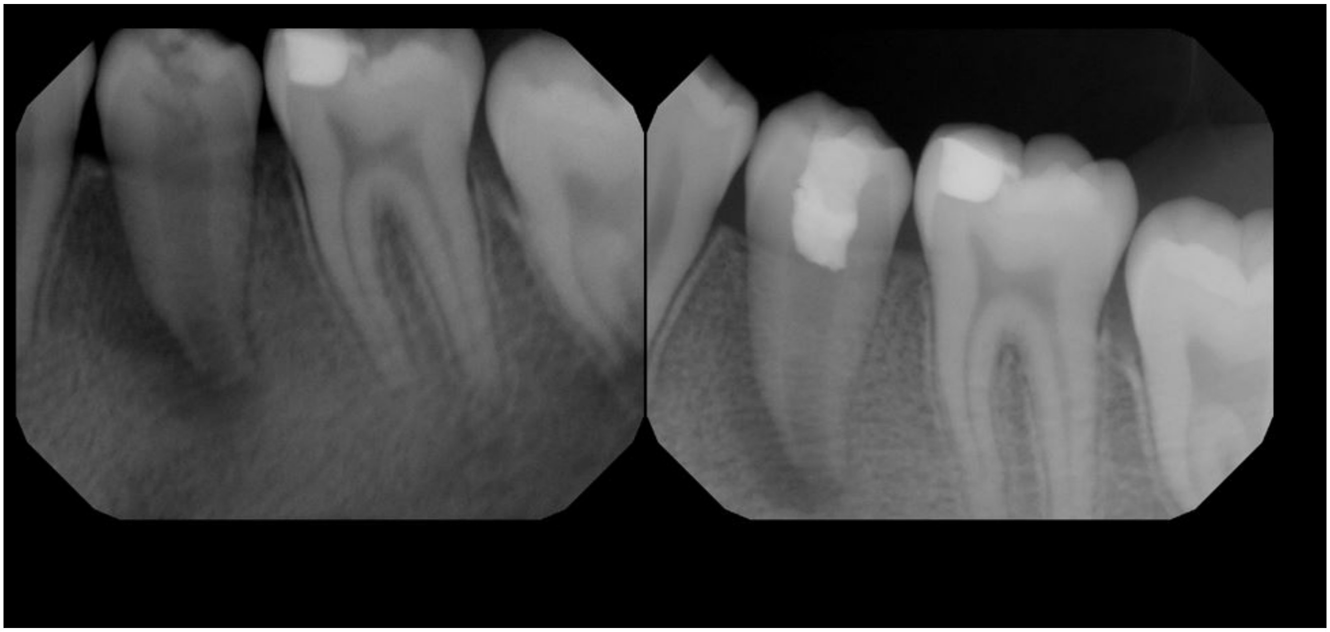


Patient 19, tooth #12

⊗ Complete Healing
◯ Incomplete Healing
◯ Failure

Patient 20

Periapicals

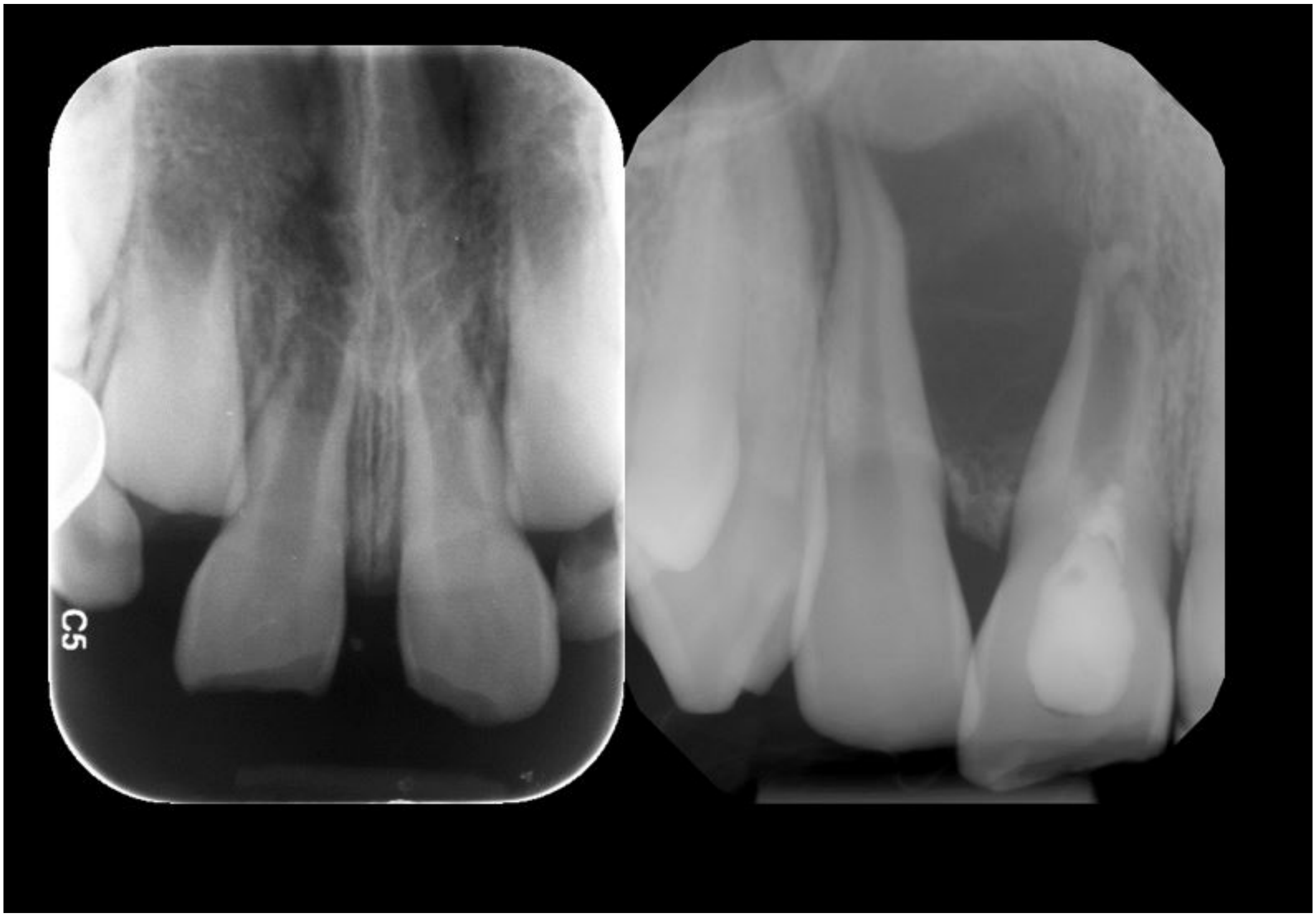


Patient 20, tooth #20

◯ Complete Healing
◯ Incomplete Healing
⊗ Failure

Patient 21

Periapicals



Patient 21, tooth #8

◯ Complete Healing
◯ Incomplete Healing
⊗ Failure

Vita

Dr. Richard W. Sedwick was born on July 1, 1982 in Harrisonburg, Virginia and is a United States citizen. He received a Bachelor of Science in Nutritional Sciences from Brigham Young University in 2006 before attending Virginia Commonwealth University School of Dentistry where he earned a Doctor of Dental Surgery in 2011. After 5 years in private practice as a general dentist, Dr. Sedwick enrolled in the Advanced Dental Program in Endodontics at Virginia Commonwealth University. He is a member of the American Dental Association and the American Association of Endodontists. Dr. Sedwick will graduate from Virginia Commonwealth University with a Master of Science in Dentistry and a Certificate in Endodontics.