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Management of the Open Apex Using a Bioceramic Apical Barrier: Success and Survival Rates at Virginia Commonwealth University

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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

MANAGEMENT OF THE OPEN APEX USING A BIOCERAMIC APICAL BARRIER; SUCCESS AND SURVIVAL RATES AT VIRGINIA COMMONWEALTH UNIVERSITY

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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, 2019

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Purpose: The aim of this study was to assess the outcome of treatment of teeth with open apices managed by the orthograde placement of a bioceramic apical barrier as well as to identify potential outcome factors for this type of treatment.

Methods: Patient records were pooled from graduate resident cases completed at Virginia Commonwealth University between January 1, 2010 and May 31, 2018. A total of 515 patients were identified using relevant ADA codes and a key word search within the patient record database. A total of 104 patients (119 teeth) had an open apex that had NSRCT utilizing a bioceramic apical barrier, with 32 of the patients (36 teeth) returning for follow-up.

Results: Of the 36 examined teeth (30.8% recall rate),72% were considered healed. 92% were considered healed or healing. No predictive variable analyzed had a significant effect on the outcome.

Conclusion: Overall, these results indicate that a bioceramic apical barrier technique is a promising treatment option for obturating teeth with open apices during NSRCT.

Introduction

The primary goal of root canal obturation is a total three-dimensional filling of the entire root canal system (1). Although the apical extent to which the root canal space is instrumented and obturated has been much debated, over-whelming evidence has shown optimum results and tissue healing when keeping the root canal filling within the confines of the root (2–5). The apical constriction has commonly been recommended as the ideal location to terminate the root canal filling material during nonsurgical endodontic treatment (2,6). The American Association of Endodontists Glossary of Terms defines the apical constriction as the apical portion of the root canal having the narrowest diameter (7). The apical constriction, also known as the minor diameter, is often located at the location for which with pulpal tissue meets periapical tissue, making it the logical position to terminate the root canal filling (8). Invasion of the apical constriction into the periapical tissue with either instrumentation or root filling material could affect apical healing (9).

For various reasons, a tooth may not have a natural apical constriction. When there is a lack of an apical constriction, the root is said to have an “open apex.” The majority of teeth with open apices are often a result of pulp necrosis that occurs during root development. After tooth eruption, it takes approximately 2 to 3 years for complete root maturation and closure of the root

apex (10). If the pulp necroses during this time, development of the root will cease, resulting in an immature open apex. Other causes leading to an open apex situation include apical resorption and iatrogenic events. Teeth with necrotic pulps and apical periodontitis can undergo resorption of the apex of the root, including the apical constriction. Open apices as a result of an iatrogenic event occur during the shaping of the root canal space using endodontic files larger than the diameter of the apical constriction beyond the apex of the root.

Achieving a three dimensional seal at the terminus of the root canal system can be challenging in a tooth with an open apex. One objective of instrumenting a root canal is to create a shape that can withstand the internal compressive forces of obturation and provide resistance form to contain a filling material. Without this resistance form, achieving an adequate apical seal and preventing obturation material from extruding beyond the confines of the canal is difficult. In addition to attaining a three-dimensional fill, moisture contamination in these cases with an open apex further contribute to the breakdown of the apical seal. An unsatisfactory apical seal can lead to an ingress or egress of tissue irritants and bacteria, which can compromise the long term outcome of treatment.

The traditional protocol for treating a tooth with an open apex is through the use of long-term apexification using a calcium hydroxide medicament prior to obturating the canal with gutta percha. This technique was first introduced by Kaiser in 1964 and then later popularized by Frank in 1966 (11). The placement of calcium hydroxide has been shown to promote root end closure as well as have an antimicrobial effect (12,13). This long-term calcium hydroxide apexification technique has been shown to be very successful. Cvek reported that radiographic healing and hard tissue formation at the apex of the tooth was noted in 90% of the cases (14). Despite the high success rates, the apexification technique using long-term calcium hydroxide

does have several disadvantages. The time it takes to achieve root end closure using a calcium hydroxide apexification technique has been reported to be anywhere from 9 months to 18 months (14–16). During this time, the calcium hydroxide may need to be replaced multiple times prior to root end closure. Because this technique may necessitate multiple visits, it will require a high degree of compliance from the patient. In addition, the tooth may be more suspectible to coronal microleakage and fracture during this extended time with the calcium hydroxide medicament in the canal (17,18). In fact, one study even suggests that long-term treatment using calcium hydroxide may in fact weaken root dentin, potentially increasing the risk for fracture (19). For these reasons, there has been added pressure to search for alternative treatment options for teeth with necrotic pulps and open apices.

Bioceramics are biocompatible ceramic materials suitable for use in the human body (20). In the 1960s, bioceramic materials were used in the medical field to repair bone defects caused by injury or disease. The aim was to elicit minimal biological response from the physiological environment. In addition to its biocompatibility, bioceramic materials exhibited other advantageous properties such as excellent levels of chemical resistance, compressive strength, and wear resistance (21). In the early 1990s, Loma Linda University in California developed and introduced mineral trioxide aggregate (MTA) to dentistry and this material was ultimately demonstrated to be the first bioceramic material to be adopted for use in endodontics (22,23). The composition of MTA was closely related to the construction material Portland cement (24,25). Portland cements are considered to be hydraulic cements containing calcium silicate derivatives (24,25). The composition of Portland cement is primarily tricalcium silicate and dicalcium silicate with lesser proportions of tricalcium aluminate and tetracalcium aluminoferrite (26). MTA materials contain the same ingredients as Portland cement, but with

the addition of gypsum and bismuth oxide (20). Bismuth oxide was added as a radiopacifier in order to make it visible on radiographs (27). In addition, MTA materials have been reported to have a smaller mean particle size, contain less heavy metals, and they have undergone additional processing and purification compared to Portland cement (28).

MTA first drew interest in endodontics as a possible alternative root-end filling material during endodontic surgery (29). The hydraulic nature of MTA was desirable given that root-end filling materials set in a wet environment. Compared to some other traditional endodontic materials, MTA was shown to form an excellent seal due to the fact that it is dimensionally stable and may even be slightly expansive upon setting (26). The presence of moisture, specifically blood, did not affect MTA's sealing ability (30). MTA materials exhibit many additional properties that are also favorable for use in endodontics. When unset, bioceramics (such as MTA) have antibacterial properties. When fully set, they are biocompatible and even bioactive (31). When in contact with perirapical tissue, MTA has the ability to induce cementum-like hard tissue formation (32,33). Because of these desirable qualities, the use of MTA expanded to additional endodontic procedures including perforation repairs, vital pulp therapy, and in the obturation of teeth with open apices.

In teeth with open apices, the use of artificial apical barriers has long been suggested as an alternative to long-term calcium hydroxide apexification. Various materials including tricalcium phosphate, freeze-dried cortical bone, and dentin chips have been previously suggested (34–36). In 1999, Torabinejad and Chivian published an article advocating the use of mineral trioxide aggregate as an artificial apical barrier (37). Since that time, additional bioceramic materials have been developed and have been used as apical barriers in open apex scenarios. Although these new materials may vary in composition, most tend to have calcium

and silicate and all have bioactivity as a common property (38). Bioceramics have since become the material of choice in artificial apical barrier procedures (39).

A variety of methods have been proposed for the orthograde placement of a bioceramic apical barrier (40–42). Access, instrumentation, and disinfection protocols are achieved using similar techniques as in cases with a natural apical constriction. Working length determination is often determined using radiographic aids such as a working length file, master apical file, and master apical cone periapical radiograph. Combining radiography with the use of an electronic apex locator will improve the predictability of attaining an accurate working length measurement (43). Once the canal is disinfected and adequately dried, it is ready for placement of the apical barrier. An optional absorbable membrane can be placed at the root apex which serves as a stop for which the bioceramic material can be compacted against while limiting the risk of material extrusion. A wide array of vehicles have been used to introduce the bioceramic material into the canal. Amalgam carriers, Dovgan carriers (Quality Aspirators), and the MAP system (Dentsply Tulsa Specia) have the capability to place small increments of material deep into the canal sytem. Newer bioceramics such as Endosequence RRM(Brand) can be shaped and carried into the canal on a long endodontic plugger. Typically, the bioceramic material will be placed in increments and compacted in order to prevent gaps within the apical portion of the canal. Endodontic pluggers, paper points, and plastic carriers have all been used to compact each increment. Ultrasonic agitation has also been proposed for reduction of voids within the barrier (44). While there are advantages and disadvantages to each method, the principles of the final obturation are the same. In vitro, a 4-mm segment has been shown to resistant displacement from the apex as well as provide an adequate apical seal (45).

Compared to calcium hydroxide, MTA was associated with better outcomes in terms of

mean time for apical hard tissue barrier and lamina dura formation on radiographs (46), as well as being less time consuming clinically (47). The placement of the bioceramic apical barrier can be done in one visit or after a few visits with the use of a calcium hydroxide interappointment medicament (48). When compared to long-term apexification, this shorter treatment time has potential benefits. The first is patient compliance. A reduced number of visits may increase the likelihood of the patient completing endodontic treatment and getting a permanent restoration. The placement of a definitive bonded restoration with a reduced treatment time serves to increase fracture resistance of a tooth with an open apex (49). More recent studies have suggested that in addition to the use of bioceramics, placement of a fiber post to the level of the apical barrier may further improve the fracture resistance of the root (50,51).

In order to provide optimal patient care, it is important to gather outcome measures of specific dental treatments as well as to determine factors that may affect prognosis. Numerous case reports and case series have illustrated the successful use of MTA as apical barriers in teeth with open apices(39,48,52–54). Continued research is needed to evaluate the long term outcomes of bioceramic apical barriers in teeth with an open apex. New bioceramic materials are developed each year which may affect the success rates of these procedures. The aim of this study is to compare both the success and survival rate of open apex cases managed using a bioceramic apical barrier completed in the VCU Graduate Endodontic Clinic. The study will also look at the current university protocols used in apexification procedures as well as additional factors that may affect these treatment outcomes.

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Methods

Patient records for this study were pooled from resident cases completed at Virginia Commonwealth University (VCU) in the Graduate Endodontic clinic after approval from the Institutional Review Board at the university (HM20012220). Cases were selected from January 1, 2010 through May 31, 2018. 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 CDT codes established by the American Dental Association (ADA) and the American Association of Endodontists (AAE) in 2013 for apexification procedures – D3350, D3351, D3352, and D3353. Additionally, a key word search was performed for the following terms within chart notes of the prescribed time period: apical barrier, apical plug, bioceramic, open apex, and apexification. There were 515 cases were identified and reviewed as potential candidates for study.

Cases that filled the following criteria were included for analysis:

1. A permanent tooth with an open apex or immature apex diagnosed with pulp necrosis with or without clinical or radiographic signs of periapical pathology.
2. A tooth that was treated with a bioceramic apical barrier technique during nonsurgical root canal treatment (NSRCT).

3. An immediate post-treatment radiograph and follow up radiograph of at least 7 months following treatment with documentation of symptoms at appointments.

Identified cases were excluded if they failed to meet all of the inclusion criteria. Also, cases were excluded if there was not a radiographic appearance of an open apex, as defined by blunderbuss canals or wide canals with parallel to divergent walls. Teeth without adequate description of bioceramic apical barrier protocols used or without adequate recall were also excluded from the study. The initial query identified 515 patients/charts. Of the 515 charts initially identified, 411 were eliminated because a bioceramic apical barrier technique was not utilized during NSRCT. Of the 104 charts that had undergone a bioceramic apical barrier technique, 72 were lost to follow up. The final number of charts included within the parameters of the study included 32 patients with 36 teeth.

The patients who met the above criteria had treatment previously completed by endodontic residents during routine patient care. When endodontic treatment was necessary on a tooth with an open apex, an artificial apical barrier procedure with a bioceramic material was initiated. Access, instrumentation, and disinfection protocols were achieved using standard protocol for non-surgical root canal treatment. If treatment was completed over multiple visits, calcium hydroxide paste was used as an interappointment medicament. At the time of obturation, a bioceramic material (ProRoot MTA, ProRoot White MTA, Neo-MTA, EndoSequence RRM) was placed in the apical portion of the root using either a carrier (Dovgan, MAP system) or an endodontic plugger. The coronal portion of the canal was obturated with sealer and gutta percha or a bonded fiber post. In all cases, a definitive restoration was placed on the tooth.

Additional information regarding these patients were recorded, such as age, sex, tooth number, and history of regenerative or vital pulp procedures. The etiology of necrosis was

determined by reviewing patient chart records. If a definitive etiology was not identified in the historical chart review, the cause of necrosis was labeled "unknown." Additional information regarding the procedure were recorded, such as number of appointments, material choice for the apical barrier, apical barrier length, use of an apical matrix, and time of recall. Each case was then de-identified for outcome determination.

Outcome types were divided into three categories based on radiographic and clinical data on follow-up visits. Each case was assigned to one of the following groups:

1. Complete Healing: The absence of clinical signs and symptoms, absence of periapical radiolucency.
2. Partial Success/ Incomplete Healing: The absence of clinical signs and symptoms, reduction in size of periapical radiolucency.
3. Failure: Persistent clinical signs and symptoms and/or a periapical radiolucency that has remained the same or has increased in size. Or, development of a radiolucency in cases for which no radiolucency was present in the immediate post-treatment radiograph

Two board certified endodontists were calibrated to understand radiographic outcome determinants and asked to place each case into one of the three categories using a REDCap (© Vanderbilt University) survey. Radiographs of examples of each outcome were shown for normalization. If there was disagreement on outcome determination, discussion ensued until an agreement on outcome was reached. Evaluators graded radiographic healing only, without knowledge of patient symptoms or knowledge of subsequent diagnostic testing.

Statistical Methods

Results were summarized using descriptive statistics (counts, percentages). Associations between various factors and healing status were compared using Fisher's Exact test. The healing time was compared between the healing status using Kruskal-Wallis test to determine if the follow-up time was associated with the healing status. SAS EG v.6.1 (SAS Institute, Cary, NC) was used for all analyses. Statistical significance was declared at the 5% level.

Results

The results of this study begin with a description of the cases that were included for evaluation. Characteristics of the patients including age, sex, tooth number, and etiology of disease are outlined. Procedural characteristics including apical barrier material and length, use of an apical matrix, history of dental treatment, and follow-up length are also outlined. The next section highlights the outcome of using bioceramic apical barriers during NSRCT in cases with an open apex. It also highlights the healing status of teeth related to different treatment factors.

Description of the Cases

A total of 515 patients were initially identified from the time period between January 2010 and May 2018. Of these, 104 patients presented a total of 119 teeth that had an open apex treated using a bioceramic apical barrier during NSRCT. Of these, 32 patients with a total of 36 teeth were available for follow-up and are included for analysis. There were 20 males (two patients had a combined total of 6 teeth) and 12 females. The median age of the patient was 17 years old (range = 7 – 62 years old). Predominantly, the teeth treated were maxillary central incisors (N=13, 36% tooth #8; N=10, 28% tooth #9). Maxillary anterior teeth (#'s 7-10) accounted for 75% (27/36) of the treated cases. The distribution of tooth type is shown in Figure 1. The primary etiology of disease was a history of trauma (58%). Of the 21 cases that had undergone prior trauma, 16 had a history of luxation or concussion and 5 had a history of

avulsion. This accounts for 44% and 14% of the cases, respectively. The etiology of disease is shown in Table 1. Primary NSRCT was the treatment rendered for 32 teeth (89%), while non-surgical retreatment was completed on 4 teeth (11%). Three of the teeth had undergone prior regeneration procedures and one of the teeth had undergone prior vital pulp therapy. Nine (25%) of the cases were completed in one appointment, while 27 (75%) of the cases were completed in multiple visits (2 or 3 appointments). An internal collagen matrix was placed in 9 of the 36 cases (25%). The median recall time occurred at 18 months. Of the 36 cases, 28 (78%) had greater than a one year follow-up length. Fifteen of these cases (42% overall) had greater than a two-year follow-up length.

Highlights of the Outcomes

A total of 36 cases were included for analysis. Two calibrated endodontists reviewed the cases and assessed the healing status and the presence of a lesion based on radiographs. The interrater agreement was assessed using Kappa statistic, κ=0.57, with raters disagreeing on 12 of the 72 ratings (36 healing status and 36 lesion presence). All cases of disagreement were discussed and consensus was reached.

The majority of cases were deemed to have complete healing (n=26, 72%), 19% (n=7) were incomplete healing and 8% were failures (n=3). Healing status was not significantly associated with healing time, gender, etiology, treatment, bioceramic material, number of appointments, use of an internal collagen matrix, presence of an immediate post-treatment lesion, or age (categorized as 18 and under or over 18). Results are given in Table 2.

Figure 1: Distribution of Tooth Type

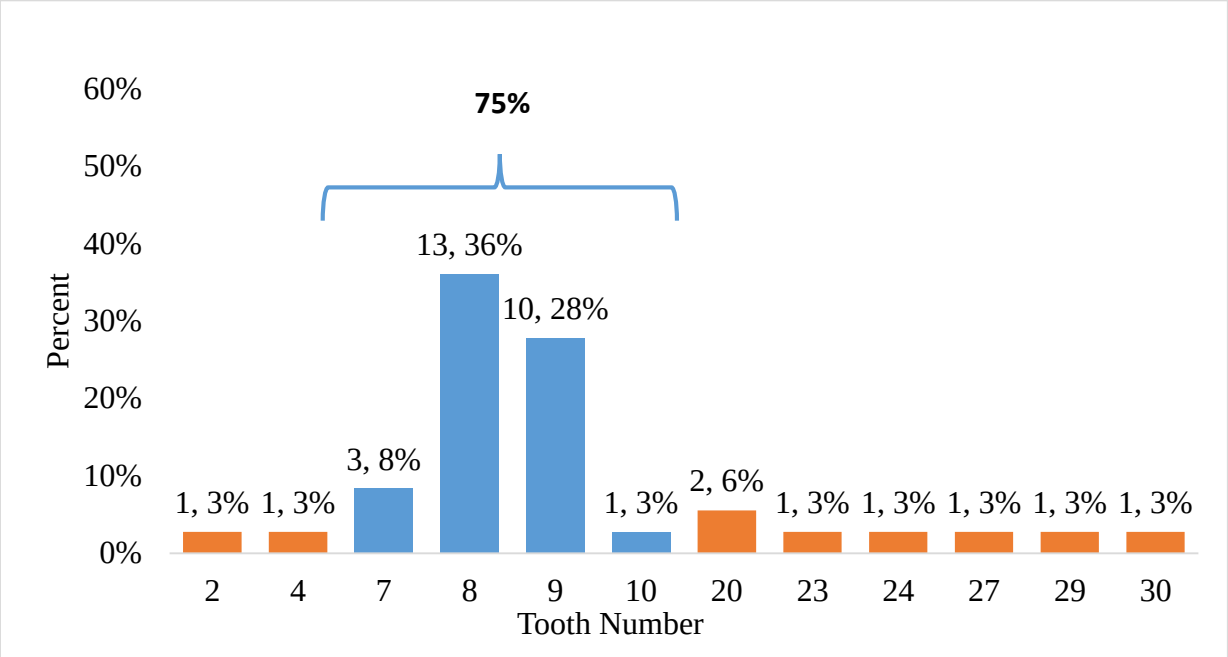

Table 1: Etiology of Disease

Etiology	Frequency	Percent	
Trauma	16	44	58%
Avulsion	5	14	
Apical Resorption	2	6	
Caries	2	6	
Dens Invaginatus	2	6	
Dens Evaginatus	1	3	
Amelogenesis imperfecta	1	3	
Iatrogenic	1	3	
Rickets	4	11	
Unknown	2	6	

Table 2: Association with Healing Status

Characteristics (Total #)	Complete	Incomplete	Failure	P-value*
Recall Time Median (IQR)	18.5 (12-35)	17 (11-42)	18 (12-30)	0.9558
Gender				0.8427
Male (24)	18 (75%)	4 (17%)	2 (8%)	
Female (12)	8 (67%)	3 (25%)	1 (8%)	
Treatment				0.3048
NSRCT (32)	24 (75%)	5 (16%)	3 (9%)	
NSReTx (4)	2 (50%)	2 (50%)	0 (0%)	
Imm. Post Treatment Lesion				0.0686
Yes (29)	21 (72%)	7 (24%)	1 (3%)	
No (7)	5 (71%)	0 (0%)	2 (29%)	
Treatment Visits				0.0536
Single (9)	4 (44%)	4 (44%)	1 (11%)	
Multiple (27)	22 (81%)	3 (11%)	2 (7%)	
Age Group				0.3507
18 and under (27)	21 (78%)	4 (15%)	2 (7%)	
Over 18 (9)	5 (56%)	3 (33%)	1 (11%)	

* P-value from Kruskal-Wallis test (Recall time) or Fisher's Exact Test

Discussion

The primary purpose for this retrospective clinical study was to assess the outcome of treatment of teeth with open apices managed by orthograde placement of a bioceramic apical barrier. An important aspect of this outcome assessment was to compare the results against the outcomes of long-term calcium hydroxide apexification treatment. Apexification using long term calcium hydroxide historically has been a successful treatment approach for teeth with open apices. Success rates have ranged from 79% to 96% (55,56). When directly comparing the two treatment techniques, El Meligy et al. (57) showed no statistical difference in both clinical and radiographic healing. At 12-month recalls, 13 of 15 teeth treated with long-term calcium hydroxide were deemed successful, while 15 of 15 teeth treated with an MTA apical barrier were successful. Although the difference was not statistically significant, it does show that a bioceramic apical barrier is a suitable alternative to long-term calcium hydroxide apexification.

In the present study, 72% of VCU cases showed an absence of clinical symptoms and periapical pathology at recall, with an additional 19% showing an absence of clinical symptoms and signs of radiographic healing. Overall, 92% of the cases were asymptomatic and functional. As a whole, the complete healing percentages are lower than those reported for long-term calcium hydroxide apexification. One possible explanation is the length of recall. In the current study, the recall ranged from 7 to 89 months with a median recall time of 18 months. Orstavik et

al. reported that although signs of healing can often be seen at 1 year, complete radiographic healing can take up to 4 years (58). In the present study, 22% had less than a 1 year follow-up visit and 58% had less than a 2 year follow-up visit. Pace et. al. exhibited a significant increase in radiographic healing between 1 year and 5 years, suggesting that longer recall lengths might be a notable factor for more favorable treatment outcomes (59). While there was no significant association between healing status and healing time in the present study, a longer recall time may have an impact on the treatment outcomes.

Determining success in root canal therapy has always been a challenge within the specialty of endodontics. Historically, endodontic treatment was not deemed successful unless there was an absence of clinical signs and symptoms as well as complete radiographic healing. Many factors can affect the rate of radiographic healing including the initial size of the lesion, patient age, and immune status of the patient. In addition, interpretation of the radiographic healing can vary among practitioners. In the present study, two board certified endodontists reviewed each periapical radiograph for presence of a periapical radiolucency at the time of treatment completion as well as the healing status at the time of recall. For the presence of a lesion at the completion of treatment, there was an 86% agreement rate. For the healing status, the two reviewers had an initial agreement on 81% of the cases. In the areas of disagreement, the two reviewers discussed these cases and consensus was reached. Radiographic interpretation and rate of healing are two reasons for which the definition of endodontic success has come into question. In 1966, Donabedian questioned the definition of quality in medical care and the approaches to its assessment (60). In the 1990's, Sackett indirectly looked into quality assessment in the medical field. He introduced the idea of evidence-based medicine and its focus on the integration of individual clinical expertise with the best available external clinical

evidence from systematic research in making the decisions about the care of individual patients (61). Recently, there has been a shift towards patient centered outcomes in endodontics. In 2003, Dugas et. al. evaluated the quality of life and satisfaction outcomes of endodontic treatment (62). Endodontic outcome studies now often take the patient's quality of life and satisfaction of treatment into account and evaluate both success rates and survival rates. In endodontic outcomes, survival typically implies that the treated tooth is present, asymptomatic, and functional at the time of evaluation. If a radiographic lesion was present at the time of treatment, a reduction in size at the time of recall would be indicative of healing or incomplete healing. In the present study, 7 of the 36 cases (19%) had a reduction, but not complete resolution, of the radiographic lesion. Because the radiographic lesion had not completely resolved, these cases were classified as Incomplete Healing. When combined with the 26 cases classified as Complete Healing, the overall healed/healing rate was 92% (33 of 36 cases). With a 92% healed/healing rate, the results of the present study are similar to other recent bioceramic apical barrier outcome studies. Holden et. al. and Witherspoon et. al. reported an overall survivability rate of 90% and 92%, respectively (39,48).

Three of the 36 cases were classified into the Failed category. All of the failures had a minimum of 12 months recall length and there were no strong correlations to be noted within this healing category. The first tooth, observation #34, was a maxillary incisor (tooth #8) and had a history of avulsion. The tooth had an extra-oral time of 2.5 hours for which the first hour was dry. Initiation of root canal treatment was not started until 5 weeks post-avulsion. Evidence of resorption was noted at the time of treatment. The quality of fill of the bioceramic apical barrier was not as dense compared to other cases within the study. Because the tooth was asymptomatic with no clinical signs or symptoms, the patient and his parents elected no further treatment. The

second cases (tooth #9) categorized as Failure, observation #35, had a history of traumatic luxation occurring over 10 years prior. At the time of endodontic treatment, the periapical radiolucency was 5mm x 5mm and had an appearance consistent with a through and through lesion. The width of opening of the apex was greater than 3mm with very thin root wall thickness at the apex. At the time of recall (18 months), a draining sinus tract was noted on the hard palate tissue in the area of tooth #8. The patient opted for root end surgery, during which time a root dentin fracture was noted near the apex of the tooth. In the third failure (tooth #8), the patient had vitamin D resistant Rickets. The recall length for this case was 30 months. Interestingly, the same patient accounted for 3 other teeth in the present study which all were classified within the Complete Healing category. Because the tooth was asymptomatic with no clinical signs or symptoms and the radiographic lesion had not increased in size, the patient and his parents opted for no further treatment. With the addition of these 2 radiographic failures with no clinical signs or symptoms, the overall survival rate of the cases in this study was 97% (35 out of 36).

Healing status was not significantly associated with the etiology of the disease. While there were no significant findings noted in the present study, some points of data were notable. 27 cases (75%) were maxillary anterior teeth. The etiology of 21 of the 36 cases (58%) was a history of trauma. Of the 21 cases with a history of trauma, 5 cases (14%) had a history of avulsion. Four of the 5 (80%) avulsion cases were classified as Complete Healing at the time of recall, with 1 case categorized as a Failure. The majority of the trauma cases involved the maxillary anterior teeth (90%) and consisted of patients under the age of 18 years old (81%). Given the age of the patients and their propensity for oral facial trauma, proficient management of the open apex is critical to the long-term retention of these teeth. Developmental

abnormalities contributed to 4 cases in the present study. These included amelogenesis imperfecta, dens invaginatus, and dens evaginatus. All four of these teeth were present, asymptomatic, and functional at the time of follow-up. Two of the teeth were classified as Complete Healing and two of the teeth were classified as Incomplete Healing. Vitamin D resistant Rickets was the etiology for 1 patient with 4 teeth included in the study. Patients with Rickets are prone to apical abscesses which often do not respond favorably to endodontic treatment (63).

Healing status was also not significantly associated with age, gender, treatment history, apical barrier material, use of an internal collagen matrix, and presence of an immediate post-treatment periapical lesion. A version of MTA (grey or white) was used in 32 of the 36 cases. The use of MTA for bioceramic apical barriers is common as it has been the most researched of the bioceramic materials on the market. An internal collagen matrix was used in 9 of the 36 cases (25%). The intended use for the collagen matrix is to aid in length control, help maintain the bioceramic material within the canal, and to reduce excess moisture during placement of the bioceramic apical barrier. In the present study, placement of an internal collagen matrix did not significantly affect the healing status. Four of the 36 cases (11%) were endodontic retreatment cases. The etiology of disease for these teeth was unknown for 2 cases, iatrogenic for 1 case, and apical resorption for 1 case. Twenty-nine of the 36 cases (81%) had a periapical radiolucency present at the time of endodontic treatment. Although not statistically significant, 2 of the 3 failures did not have a radiographic lesion present at time of treatment.

The shorter treatment time with bioceramic apical barriers can be advantageous for multiple reasons. Treatments requiring several visits, such as long-term calcium hydroxide apexification, have an increased risk of patient fatigue and attrition. According to Kinirons et al.,

teeth that were more frequently dressed with calcium hydroxide would result in an earlier detection of a calcific apical barrier (64). For a calcific barrier formation within 9 months, it was recommended to have the calcium hydroxide replaced every 3 months or sooner. Given that the majority of patients undergoing these treatments are under the age of 18, longer treatment times with multiple appointments can be difficult with the busy schedules of both the parent and the child. These appointments are often easily forgotten or postponed because the teeth are asymptomatic. Conversely, endodontic treatment with the use of a bioceramic apical barrier can be completed in as little as one or two visits. Additionally, long-term calcium hydroxide apexfication requires the patient to be without a definitive restoration for a longer period of time. Because of the thin cervical dentin in teeth with immature roots, there is an increased susceptibility to root fracture (65). Bioceramic apical barrier techniques reduce the amount of time that this fragile immature root dentin is exposed to the occlusal forces that could ultimately lead to root fracture. A definitive bonded restoration, which can improve the fracture resistance, can be placed after just one or two visits with this apical barrier technique (49).

In more recent times, the use of Regenerative Endodontic Procedures (REPs) have been advocated for the treatment of teeth with necrotic pulps and open apices. In 2016, a retrospective case series by Bukhari et. al out of the University of Pennsylvania reported complete healing in 75% (21 of 28) of cases. In a recent systematic review by Tong, 94% of REP cases showed an elimination of symptoms and evidence of bony healing (66). While promising, there is limited research on the long-term outcomes of regenerative endodontic therapy. In addition, there has been an evolution of the materials and techniques used during regenerative procedures which hinders a proper comparison between different studies. While the elimination of symptoms and periapical pathosis is the primary goal of REPs, a secondary goal is continued root maturation

resulting in an increase in canal wall thickness and length. The potential for continued root development is the main advantage of regenerative endodontic procedures over bioceramic apical barriers. Theoretically, increasing root thickness in the cervical portion of the root could decrease the risk for catastrophic root fracture. But while multiple studies show that the resolution of periapical disease is reliably achievable using REPs, the secondary goal of increased root maturation appears to be less predictable (67). A recent study using cone beam computed tomography showed that in addition to being unpredictable, the root development that did occur after REPs had variable patterning of radiopaque deposits different from typical root development (68). Teeth that fail to exhibit increased cervical root dentin thickness or present with a defective pattern of development may still remain susceptible to root fracture. To reduce the risk of fracture in these cases, a bioceramic apical barrier technique with a subsequent placement of a bonded fiber post may be indicated. In the current study, 8% (3 of 36) of the cases had a prior regenerative endodontic procedure prior to placement of a bioceramic apical barrier. In each of these cases, the outcome of the procedure was successful.

Limitations of the present study include sample size and healing times. Of the 104 patients receiving a bioceramic apical barrier procedure, 32 patients were available for follow-up. This equates to a 31% recall rate of at least 7 months or longer. All patients were treated by endodontic residents in the Graduate Endodontic clinic at Virginia Commonwealth University. The majority of the patients were minors requiring a parent to accompany them to the appointment. Recalling these patients had increased difficulty with the busy schedule of both school aged children and parents. With the median recall time being 18 months, additional healing time could provide more accurate long term outcome results. An additional limitation to the study was the format used by the raters to evaluate radiographic healing. For standardization,

the raters compared two still digital photographs (.jpgs). A more thorough evaluation may have been completed using image enhancing tools provided with digital imaging software.

Conclusion

Data collected from this retrospective chart review spanned a time frame of 8 years, yielding 36 cases of open apices treated using a bioceramic apical barrier technique. With a recall rate of 31%, establishing a recall time frame early and committing providers, patients, and the guardians of patients to a series of recalls will be essential to better understand the outcomes of this procedure. Based on the current study, the results indicate that a bioceramic apical barrier technique is a predictable and successful method for obturating teeth with open apices during nonsurgical endodontic treatment. Although healing status was not significantly associated with any of the outcome predictors tested, some factors show trend towards significance and should be studied with larger sample size. Because few studies exist, increased power could be gained by means of meta-analysis or multi-centered studies. Additionally, comparative studies using both bioceramic apical barrier techniques and regenerative endodontic procedures would help determine long term outcomes, advantages, risk, and clinical indications for each procedure.

References

1 Schilder H, Hargreaves KM. Filling root canals in three dimensions. J Endod 2006;32(4):281–90.

2 Wu MK, Wesselink PR, Walton RE. Apical terminus location of root canal treatment procedures. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000;89(1):99–103.

3 Schaeffer MA, White RR, Walton RE. Determining the optimal obturation length: A meta-analysis of literature. J Endod 2005;31(4):271–4.

4 Stein TJ, Corcoran JF. Radiographic "working length" revisited. Oral Surgery, Oral Med Oral Pathol 1992;74(6):796–800.

5 Sjögren U, Hägglund B, Sundqvist G, Wing K. Factors affecting the long-term results of endodontic treatment. J Endod 1990;16(10):498–504.

6 Kuttler Y. Microscopic investigation of root apexes. J Am Dent Assoc 1955;50(5):544–52.

7 Anonymous. Glossary of Endodontic Terms 2016. Glossary of Endodontic Terms. Available at: http://www.nxtbook.com/nxtbooks/aae/endodonticglossary2016/#/0. Accessed February 19, 2019, 2015.

8 Ponce EH, Vilar Fernández JA. The cemento-dentino-canal junction, the apical foramen, and the apical constriction: Evaluation by optical microscopy. J Endod 2003;29(3):214–9.

9 Cohen Stephen, Hargreaves Kenneth M. *Pathways of the Pulp*. 2006.

10 Logan WHG, Kronfeld R. Development of the Human Jaws and Surrounding Structures from Birth to the Age of Fifteen Years**From the Research Department of the Chicago College of Dental Surgery, Dental Department of Loyola University.Read at the Third General Meeting of the Seventy. J Am Dent Assoc 2015;20(3):379–428.

11 Frank AL. Therapy for the divergent pulpless tooth by continued apical formation. J Am Dent Assoc 1966;72(1):87–93.

12 Sjögren U, Figdor D, Spanberg L, Sundqvist G. The antimicrobial effect of calcium hydroxide as a short-term intracanal dressing. Int Endod J 1991;24(3):119–25.

13 Heithersay GS. Stimulation of root formation in incompletely developed pulpless teeth. Oral Surgery, Oral Med Oral Pathol 1970;29(4):620–30.

14 Cvek M. Treatment of non-vital permanent incisors with calcium hydroxide. I. Follow-up

of periapical repair and apical closure of immature roots. Odontol Rev 1972:23:27-44.

15 Yates JA. Barrier formation time in non-vital teeth with open apices. Int Endod J 1988;21(5):313–9.

16 Kleier DJ, Barr ES. A study of endodontically apexified teeth. Dent Traumatol 1991;7(3):112–7.

17 Magura ME, Kafrawy AH, Brown CE, Newton CW. Human saliva coronal microleakage in obturated root canals: An in vitro study. J Endod 1991;17(7):324–31.

18 HA Ray, Trope M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. Int Endod J 1995;28(1):12–8.

19 Andreasen Jens Ove, Farik Ban, Munksgaard Erik Christian. Long-term calcium hydroxide as a root canal dressing may increase risk of root fracture. Dent Traumatol 2002;18(3):134–7.

20 Wang Z. Bioceramic materials in endodontics. Endod Top 2015;32(1):3–30.

21 Best SM, Porter AE, Thian ES, Huang J. Bioceramics: Past, present and for the future. J Eur Ceram Soc 2008;28:1319–27.

22 Abedi HR, Ingle JI. Mineral trioxide aggregate: a review of a new cement. J Calif Dent Assoc 1995;23(12):36–9.

23 Torabinejad M, Hong CU, McDonald F, Pitt Ford TR. Physical and chemical properties of a new root-end filling material. J Endod 1995;21(7):349–53.

24 Islam I, Kheng Chng H, Jin Yap AU. Comparison of the physical and mechanical properties of MTA and portland cement. J Endod 2006;32(3):193–7.

25 Funteas UK, Wallace JA, Fochtman FW. A comparative analysis of mineral trioxide aggregate and portland cement. Aust Endod J 2003;29(1):43–4.

26 Jefferies SR. Bioactive and biomimetic restorative materials: A comprehensive review. part I. J Esthet Restor Dent 2014:14–24.

27 Beyer-Olsen EM, Ørstavik D. Radiopacity of root canal sealers. Oral Surgery, Oral Med Oral Pathol 1981;51(3):320–8.

28 Roberts HW, Toth JM, Berzins DW, Charlton DG. Mineral trioxide aggregate material use in endodontic treatment: A review of the literature. Dent Mater 2008:149–64.

29 Haapasalo Markus, Parhar Mark, Huang Xiangya, Wei Xi, Lin James, Shen Ya. Clinical use of bioceramic materials. Endod Top 2015;32(1):97–117.

30 Torabinejad M, Higa RK, McKendry DJ, Pitt Ford TR. Dye leakage of four root end filling materials: Effects of blood contamination. J Endod 1994;20(4):159–63.

31 Parirokh M, Torabinejad M. Mineral Trioxide Aggregate: A Comprehensive Literature Review-Part I: Chemical, Physical, and Antibacterial Properties. J Endod 2010;36(1):16–27.

32 Shabahang S, Torabinejad M, Boyne PP, Abedi H, McMillan P. A comparative study of root-end induction using osteogenic protein-1, calcium hydroxide, and mineral trioxide aggregate in dogs. J Endod 1999:1–5.

33 Apaydin ES, Shabahang S, Torabinejad M. Hard-tissue healing after application of fresh or set MTA as root-end-filling material. J Endod 2004;30(1):21–4.

34 Tronstad L. Tissue reactions following apical plugging of the root canal with dentin chips in monkey teeth subjected to pulpectomy. Oral Surgery, Oral Med Oral Pathol 1978;45(2):297–304.

35 Coviello J, Brilliant JD. A Preliminary Clinical Study on the Use of Tricalcium Phosphate as an Apical Barrier. J Endod 1979;5(1):6–13.

36 Rossmeisl R, Reader A, Melfi R, Marquard J. A study of freeze-dried (lyophilized) dentin used as an apical barrier in adult monkey teeth. Oral Surgery, Oral Med Oral Pathol 2005;53(3):303–10.

37 Torabinejad M, Chivian N. Clinical applications of mineral trioxide aggregate. J Endod 1999;25(3):197–205.

38 Torabinejad M, Parirokh M, Dummer PMH. Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview – part II: other clinical applications and complications. Int Endod J 2018:284–317.

39 Holden DT, Schwartz SA, Kirkpatrick TC, Schindler WG. Clinical Outcomes of Artificial Root-end Barriers with Mineral Trioxide Aggregate in Teeth with Immature Apices. J Endod 2008;34(7):812–7.

40 Aminoshariae A, Hartwell GR, Moon PC. Placement of mineral trioxide aggregate using two different techniques. J Endod 2003;29(10):679–82.

41 Yeung Priscilla, Liewehr Frederick R, Moon Peter C. A Quantitative Comparison of the Fill Density of MTA Produced by Two Placement Techniques. J Endod 2006;32(5):456–9.

42 Giovarruscio M, Uccioli U, Malentacca A, Koller G, Foschi F, Mannocci F. A technique for placement of apical MTA plugs using modified Thermafil carriers for the filling of canals with wide apices. Int Endod J 2013;46(1):88–97.

43 Kim Y JA, Chandler NP. Determination of working length for teeth with wide or immature apices: A review. Int Endod J 2013:483–91.

44 Lawley G, Schindler W, Walker III W, Kolodrubetz D. Evaluation of Ultrasonically Placed MTA and Fracture Resistance with Intracanal Composite Resin in a Model of Apexification. J Endod 2004;30(3):167–72.

45 Hachmeister DR, Schindler WG, Walker WA, Thomas DD. The sealing ability and retention characteristics of mineral trioxide aggregate in a model of apexification. J Endod 2002;28(5):386–90.

46 Chala S, Abouqal R, Rida S. Apexification of immature teeth with calcium hydroxide or

mineral trioxide aggregate: Systematic review and meta-analysis. Oral Surgery, Oral Med Oral Pathol Oral Radiol Endodontology 2011.

47 Lin JC, Lu JX, Zeng Q, Zhao W, Li WQ, Ling JQ. Comparison of mineral trioxide aggregate and calcium hydroxide for apexification of immature permanent teeth: A systematic review and meta-analysis. J Formos Med Assoc 2016;115:523–30.

48 Witherspoon DE, Small JC, Regan JD, Nunn M. Retrospective Analysis of Open Apex Teeth Obturated with Mineral Trioxide Aggregate. J Endod 2008;34(10):1171–6.

49 Pene JR, Nicholls JI, Harrington GW. Evaluation of fiber-composite laminate in the restoration of immature, nonvital maxillary central incisors. J Endod 2001;27(1):18–22.

50 Schmoldt SJ, Kirkpatrick TC, Rutledge RE, Yaccino JM. Reinforcement of simulated immature roots restored with composite resin, mineral trioxide aggregate, gutta-percha, or a fiber post after thermocycling. J Endod 2011;37(10):1390–3.

51 Desai S, Chandler N. The restoration of permanent immature anterior teeth, root filled using MTA: A review. J Dent 2009:652–7.

52 Moore A, Howley MF, O'Connell AC. Treatment of open apex teeth using two types of white mineral trioxide aggregate after initial dressing with calcium hydroxide in children. Dent Traumatol 2011;27(3):166–73.

53 Annamalai S, Mungara J. Efficacy of Mineral Trioxide Aggregate as an Apical Plug in Non-Vital Young Permanent Teeth: Preliminary Results. J Clin Pediatr Dent 2015;35(2):149–55.

54 Mente J, Leo M, Panagidis D, et al. Treatment outcome of mineral trioxide aggregate in open apex teeth. J Endod 2013;39(1):20–6.

55 Kerekes K, Heide S, Jacobsen I. Follow-up examination of endodontic treatment in traumatized juvenile incisors. J Endod 1980;6(9):744–8.

56 Cvek M. Prognosis of luxated non-vital maxillary incisors treated with calcium hydroxide and filled with gutta-percha. A retrospective clinical study. Dent Traumatol 1992;8(2):45–55.

57 El Meligy OAS, Avery DR. Comparison of apexification with mineral trioxide aggregate and calcium hydroxide. Pediatric Dentistry 2006;28(3):248-253.

58 Ørstavik D. Time-course and risk analyses of the development and healing of chronic apical periodontitis in man. Int Endod J 1996;29(3):150–5.

59 Pace Riccardo, Giuliani Valentina, Nieri Michele, Di Nasso Luca, Pagavino Gabriella. Mineral trioxide aggregate as apical plug in teeth with necrotic pulp and immature apices: A 10-year case series. J Endod 2014.

60 Donabedian A. Evaluating the Quality of Medical Care. Milbank Mem Fund Q 1966;44(3):166.

61 Sackett DL, Rosenberg WM, Gray JA, Haynes RB, Richardson WS. Evidence based medicine: what it is and what it isn't. BMJ 1996;312(7023):71–2.

62 Dugas NN, Lawrence HP, Teplitsky P, Friedman S. Quality of Life and Satisfaction Outcomes of Endodontic Treatment. J Endod 2002;28(12):819–27.

63 Bender IB, Naidorf IJ. Dental observations in vitamin D-resistant rickets with special reference to periapical lesions. J Endod 1985;11(11):514–20.

64 Kinirons MJ, Srinivasan V, Welbury RR, Finucane D. A study in two centres of variations in the time of apical barrier detection and barrier position in nonvital immature permanent incisors. Int J Paediatr Dent 2001;11(6):447–51.

65 Kahler SL, Shetty S, Andreasen FM, Kahler B. The Effect of Long-term Dressing with Calcium Hydroxide on the Fracture Susceptibility of Teeth. J Endod 2018;44(3):464–9.

66 Tong HJ, Rajan S, Bhujel N, Kang J, Duggal M, Nazzal H. Regenerative Endodontic Therapy in the Management of Nonvital Immature Permanent Teeth: A Systematic Review—Outcome Evaluation and Meta-analysis. J Endod 2017;43(9):1453–64.

67 Kim SG, Malek M, Sigurdsson A, Lin LM, Kahler B. Regenerative endodontics: a comprehensive review. Int Endod J 2018;51(12):1367–88.

68 Linsuwanont P, Sinpitaksakul P, Lertsakchai T. Evaluation of root maturation after revitalization in immature permanent teeth with nonvital pulps by cone beam computed tomography and conventional radiographs. Int Endod J 2017;50(9):836–46.