Retrospective Evaluation of Perforation Repairs in 6 Private Practices

Valérie Pontius, DMD,* Oliver Pontius, DMD, MSD,† Andreas Braun, DMD, PhD,* Roland Frankenberger, DMD, PhD, FICD, FADM,* and Matthias Johannes Roggendorf, DMD*

Abstract

Introduction: The purpose of this study was to investigate retrospectively the clinical outcome of 70 perforation repairs performed by 6 endodontic specialists. **Methods:** Endodontic specialists performed a total of 70 perforation repairs (69 patients) between 1998 and 2010 using a nonsurgical or combined nonsurgical/surgical approach. Treatments were performed with the aid of a dental operating microscope. Recalls of at least 6 months were obtained on 49 patients (50 teeth). Two calibrated observers evaluated the radiographic results on recalls up to 116 months, with a mean of 37 months. Pre-, intra-, and postoperative data were evaluated with respect to treatment outcomes and possible prognostic factors. **Results:** Successful results were obtained in 45 of 50 perforation repairs, a success rate of 90%. Significant prognostic factors included the location of the perforation, sex of the patient, and restorative status of the tooth before perforation repair. The overall success rate of this study was higher than reported in other studies. **Conclusions:** Perforation repairs can be performed with a high level of success at least in the short- to medium-term. *(J Endod 2013;39:1346–1358)*

Key Words

Mineral trioxide aggregate, perforation repair, root perforation, treatment outcome

From the *Department of Operative Dentistry and Endodontics, Dental School, University of Marburg and University Medical Center Giessen and Marburg, Campus Marburg, and †Private Endodontic Practice, Bad Homburg, Germany.

Address requests for reprints to Dr Matthias Johannes Roggendorf, Department of Operative Dentistry and Endodontics, Dental School, Philipps University of Marburg and University Medical Center Giessen and Marburg, Campus Marburg, Georg-Voigt-Str 3, 35039 Marburg, Germany. E-mail address: matthias.roggendorf@staff.uni-marburg.de

0099-2399/$ - see front matter

http://dx.doi.org/10.1016/j.joen.2013.08.006

The occurrence of perforations during endodontic treatment is reported to range from 2.3%–12% (1, 2). Kvinnsland et al (2) reported an increased risk for perforations in the upper jaw (73%) compared with lower teeth, whereas Tsesis et al (3) reported that 55% of perforations occurred in lower molar teeth.

Crown-root angulations, calcifications of the pulp chamber and orifices, anatomic variations, and excessive removal of coronal dentin may contribute to perforations in the coronal part of the tooth (4). Excessive flaring and overzealous instrumentation of curved roots may result in coronal or midroot perforations. Apical perforations may be the consequence of inappropriate cleaning and shaping techniques and are sometimes initiated by blocked and transported canal systems (5). These may be the most challenging to repair because of limited visibility and access (6). Oversized and poorly angulated post space preparations may also result in root perforations (4).

Perforations lead to inflammation and the destruction of periodontal fibers and alveolar bone and can cause a periodontal defect (7). It is important to diagnose and repair perforations immediately if possible.

Existing perforations are often identified during the diagnostic phase on radiographs taken from different angles and during the periodontal assessment of the tooth. Cone-beam computed tomographic imaging may be helpful to determine whether a perforation exists, to localize the perforation, and to decide on treatment options (8). Perforation repair may be accomplished nonsurgically, from inside the tooth, or with a surgical approach (6, 9).

Factors reported to affect the prognosis of repair include immediacy, location, size, and previous microbial contamination (10). The location of the perforation is probably the most critical prognostic factor. Perforations in the apical or middle third of the root have a better prognosis than those in the cervical third or floor of the chamber. Root perforations at the alveolar crest exhibit the poorest prognosis because of potential microbial contamination and periodontal breakdown (10).

Mineral trioxide aggregate (MTA) is reported to be the material of choice for perforation repair (4, 11, 12). MTA is composed of calcium, silica, and bismuth. Its biocompatibility is well documented (13). It possesses some antibacterial and antifungal properties, is a bioactive material that modulates cytokine production, and encourages the differentiation and migration of hard-tissue producing cells. MTA releases calcium ions for cell attachment and proliferation and creates an antibacterial environment because of its alkaline pH. It forms $Ca(OH)_2$ on its surface and provides a "biologic" seal (14), meaning that under ideal conditions cementum will grow over it.

MTA has some disadvantages. It has a long setting time of about 4 hours, which makes it inappropriate for exposure to the oral cavity (6). MTA can cause discoloration and should not be used in the aesthetic zone (15).

Perforations are reported to lower the prognosis of endodontic treatment to 54%–56% (16, 17). In a study by Mente et al (18), 86% success was reported. However, this study was based on a very small sample size (21 teeth) and short recall periods (13–65 months). Therefore, the long-term prognosis for perforations cannot be determined from this study.

There are case reports on successful perforation repairs up to 13 years (19, 20), but there are no studies with adequate sample sizes and long-term data. These data would be valuable for decision making and treatment planning when deciding whether to repair or extract.

There is a dearth of studies in the endodontic literature that evaluate the outcome of clinical procedures, including perforation repair, with evaluation periods longer than 1 or 2 years. The purpose of this retrospective study was to evaluate the healing outcome of perforation repairs performed by endodontic specialists in 6 private practices.

Materials and Methods

Seventy intra-alveolar perforations in 69 patients were identified that had been repaired by 6 endodontic specialists in their private practices between 1998 and 2010. The perforations were diagnosed clinically by visualization, bleeding spots on paper points, with an electronic apex locator, and radiographically. The location and extent of the perforations were determined.

All participating offices were using TDO practice management software (The Digital Office for Endodontists, Inc, San Diego, CA), which standardized the documentation of the evaluation, treatment, and recalls. The documentation included pulp status, electronic working length, reference point, actual working length, apical curvature, master apical file, taper of gutta-percha cone used, sealer, obturation technique, extension of the root canal filling in relation to the canal terminus, interappointment medication, and buildup materials. The following information was recorded about the perforations: canal, location of the perforation (supracrestal, crestal, and subcrestal), size, type (furcal, lateral root, and strip), cause (post, bur, endodontic instrument, internal/external resorption, and caries), prior perforation repair, time until repair, and repair material. Teeth that revealed root fractures, inadequate remaining tooth structure, or severe periodontitis were excluded a priori.

Specialist A (Germany) repaired 46 teeth; specialist B (United States, 12 teeth), specialist C (The Netherlands, 5 teeth), specialist D (Italy, 3 teeth), specialist E (Jamaica, 3 teeth), and specialist F (Ireland, 1 tooth) performed the clinical procedures between January 1998 and March 2010 using their standard clinical techniques. Nonsurgical (63 teeth) or combined nonsurgical/surgical repairs (7 teeth) were performed. A total of 70 perforation repairs were completed in the 6 practices during the time period. After considerable effort, the clinicians were able to recall 50 of the patients. Twenty patients were not available for recall. The basic data for the recalls are presented in Table 1.

All 70 patients provided informed consent for endodontic treatment, and the 50 recall patients consented to the potential use of the outcome data for publication. The patients who were included were not known to be pregnant or medically compromised.

All treatments were performed using a dental operating microscope, local anesthesia, and rubber dam isolation. Patency was confirmed in all cases with small hand files in combination with an electronic apex locator device and radiography. Cleaning and shaping were performed according to Schilder's biological and mechanical objectives (5) using stainless steel hand instruments and nickel-titanium rotary files. Irrigation was performed with 3% sodium hypochlorite (NaOCl) and 17% EDTA for smear layer removal. Calcium hydroxide was applied as an intra-canal dressing in cases associated with chronic apical periodontitis (periapical index [PAI] score 3 or above). Pure grade $Ca(OH)_2$ powder (compounding pharmacy) was freshly mixed with sterile saline in 27 cases, and the slurry was placed with a Lentulo spiral. In 21 cases, UltraCal XS was applied using a NaviTip (Ultradent Products Inc, South Jordan, UT). Ledermix (Riemser Pharma, Greifswald, Germany) was applied in 3 cases. Root canal systems were obturated with vertical compaction of warm gutta-percha (5). MTA was used for most of the perforation repairs according to the manufacturer's protocols (21).

Pre- and postoperative clinical evaluations were performed by the treating clinicians after 6 to 116 months (mean = 37 months, inclusion rate = 71.4 %). The time interval between perforation repair and recall was at least 6 months. Two calibrated investigators who were not involved in the clinical treatment graded preoperative, immediate postoperative, and recall radiographs. The images were viewed progressively over time and rated by each of the evaluators after recall appointments. In cases in which no consensus was reached, a third investigator was included to obtain a consensus score. Potential bias was reduced by blinding and random investigation of the radiographs.

Perforations were classified based on the following criteria:

1. Number of roots
2. Location of the perforation (osseous crestor sub- or supracrestal)
3. Size
4. Type (lateral, furcal, or strip)
5. Source of the perforation (bur, post, file, external or internal resorption, or caries)
6. Prior repair (yes or no)
7. Repair material
8. Time since perforation

Recall examinations included the following data:

1. Presence or absence of coronal restoration
2. Presence or absence of coronal leakage
3. Symptoms (tooth asymptomatic, functional, or symptomatic)
4. Size (increase, decrease, or stable)
5. Appearance of periodontal ligament space (normal or abnormal)
6. Palpation soreness (0–3)
7. Percussion sensitivity (0–3)
8. Tooth mobility (0–3)
9. Presence or absence of a sinus tract
10. Periodontal probing depths
11. Periapical and periradicular diagnosis according to the PAI index and root perforation index scoring system (described later)

Preoperative, postoperative, and recall radiographs were analyzed according to the following criteria:

1. *Radiologic coronal score* (Hommez et al, 2002 (22)): Score 1: intact restoration without signs of leakage (acceptable), score 2: restoration with open margin (unacceptable), and score 3: restoration with recurrent decay (unacceptable)
2. *Length of root canal filling score* (Hommez et al, 2002 (22)): Score 1: root filling terminating 0–2 mm from the radiographic apex, score 2: root filling terminating >2 mm from the radiographic apex, and score 3: root filling extending beyond the radiographic apex
3. *Homogeneity of root canal filling* (Hommez et al, 2002 (22)): Score 1: homogeneous root filling, good condensation, and no voids visible and score 2: inhomogeneous root filling, poor condensation, and voids visible
4. *PAI score* (Ørstavik et al, 1986 (23)): Score 1: no structural changes in the periapical area, score 2: disorganization of the bone texture in the periapical area, score 3: structural changes in the periapical area with loss of mineral, score 4: radiolucency in the periapical area, and score 5: radiolucency with elements indicating expansion of the lesion
5. *Root perforation index (RPI) score* (introduced by Roggendorf and Pontius, 2011): Score 1: no structural changes at the site of perforation, score 2: disorganization of the bone texture at the site of perforation, score 3: structural changes at the site of perforation

TABLE 1. Overview of the Clinical Data and Treatment Procedures

Tooth type	Roots	Jaw	Sex	Age	Size of perforation	Type of perforation	Cause of perforation	Prior repair	Duration of perforation (mo)	Location of perforation	Repair material	Endodontic treatment	Perforation treatment	Recall (mo)	Success
4	1	Maxilla	Female	46	Medium	Lateral	Post	No	>1 mo	Subcrestal	MTA/Collacote	Retreatment	Nonsurgical	99	Yes
3	3	Maxilla	Female	52	Large	Furcal	Bur	No	Immediately	Crestal	MTA (Calcitek, Carlsbad, CA)	Initial treatment	Nonsurgical	15	Yes
30	2	Mandible	Male	65	Medium	Furcal	Exterior resorption	No	Immediately	Crestal	Geristore (DenMat, Santa Maria, CA)	Initial treatment	Nonsurgical	60	Yes
19	2	Mandible	Female	49	Large	Furcal	Bur	No	Unknown	Crestal	MTA	Retreatment	Nonsurgical	10	Yes
19	2	Mandible	Male	41	Large	Furcal	Post	No	>1 mo	Crestal	Geristore	Retreatment	Nonsurgical	40	Yes
25	1	Mandible	Female	64	Small	Lateral	Bur	No	<1 mo	Crestal	OptiBond/ Tetric Flow (Ivoclar Vivadent AG, Schaan, Liechtenstein)/ calcium sulfate	Initial treatment	Nonsurgical	23	Yes
14	3	Maxilla	Female	77	Medium	Furcal	Bur	No	>1 mo	Crestal	MTA	Initial treatment	Nonsurgical	18	Yes
3	3	Maxilla	Male	34	Large	Lateral	Post	No	>1 mo	Subcrestal	MTA	Retreatment	Nonsurgical	61	Yes
30	2	Mandible	Female	61	Medium	Lateral	Post	No	<1 mo	Subcrestal	MTA	Retreatment	Nonsurgical	73	Yes
24	1	Mandible	Female	23	Large	Lateral	Post	No	>1 mo	Subcrestal	MTA	Retreatment	Nonsurgical	69	Yes
11	1	Maxilla	Male	58	Medium	Lateral	Screw	Yes	>1 mo	Subcrestal	gutta-percha	Initial treatment	Nonsurgical	36	Yes
3	3	Maxilla	Female	51	Small	Furcal	Instrument	No	Unknown	Crestal	MTA	Initial treatment	Nonsurgical	6	Yes
3	3	Maxilla	Male	45	Medium	Lateral	Instrument	No	>1 mo	Subcrestal	MTA	Initial treatment	Apical surgery mb/db	31	Yes
30	2	Mandible	Female	38	Medium	Lateral	Instrument	No	>1 mo	Subcrestal	MTA	Retreatment	Nonsurgical	12	Yes
3	3	Maxilla	Male	46	Large	Furcal	Bur	No	>1 mo	Crestal	OptiBond (Kerr Corp, Orange, CA)/ Tetric Flow/ calcium sulfate	Retreatment	Nonsurgical	18	Yes
12	3	Maxilla	Male	37	Large	Furcal	Instrument	No	Unknown	Subcrestal	MTA	Retreatment	Nonsurgical	25	Yes
19	2	Mandible	Female	45	Large	Furcal	Bur	No	>1 mo	Crestal	MTA	Initial treatment	Nonsurgical	9	Yes
5	2	Maxilla	Female	38	Large	Lateral	Bur	No	Unknown	Subcrestal	MTA	Retreatment	Nonsurgical	62	Yes
24	1	Mandible	Male	18	Large	Lateral	Exterior resorption	No	>1 mo	Subcrestal	MTA	Initial treatment	Nonsurgical	9	Yes
3	3	Maxilla	Female	30	Medium	Lateral	Instrument	No	Unknown	Subcrestal	gutta-percha	Retreatment	Apical surgery mb	116	Yes
9	1	Maxilla	Female	23	Large	Lateral	Interior resorption	No	>1 mo	Subcrestal	MTA	Initial treatment	Nonsurgical	55	Yes
9	1	Maxilla	Female	34	Medium	Lateral	Instrument	No	Unknown	Subcrestal	MTA	Initial treatment	Nonsurgical	66	Yes
30	2	Mandible	Male	67	Large	Furcal	Bur	No	Unknown	Subcrestal	MTA	Retreatment	Nonsurgical	24	Yes
19	2	Mandible	Female	14	Large	Strip	Instrument	No	Unknown	Subcrestal	MTA	Retreatment	Nonsurgical	51	Yes
22	1	Mandible	Female	51	Medium	Lateral	Instrument	No	Unknown	Subcrestal	MTA	Initial treatment	Nonsurgical	60	Yes
3	3	Maxilla	Female	46	Large	Furcal	Bur	No	Immediately	Crestal	MTA	Retreatment	Nonsurgical	37	Yes
20	1	Mandible	Female	53	Large	Lateral	Bur	No	Unknown	Crestal	OptiBond/Tetric Flow/calcium sulfate	Initial treatment	Nonsurgical	15	Yes

6	1	Maxilla	Female	63	Large	Lateral	Bur	No	<1 mo	Supracrestal	OptiBond/Tetric Flow/calcium sulfate	Initial treatment	Nonsurgical	64	Yes
7	1	Maxilla	Male	55	Medium	Lateral	Instrument	No	<1 mo	Subcrestal	MTA	Retreatment	Gutta-percha removed	41	Yes
30	2	Mandible	Female	44	Large	Strip	Instrument	No	Unknown	Subcrestal	MTA	Retreatment	Nonsurgical	39	Yes
31	2	Mandible	Male	49	Medium	Lateral	Instrument	No	Unknown	Subcrestal	MTA	Retreatment	Nonsurgical	53	Yes
19	2	Mandible	Male	55	Large	Furcal	Bur	No	<1 mo	Crestal	MTA	Initial treatment	Nonsurgical	57	No
20	1	Mandible	Female	50	Small	Lateral	Bur	No	<1 mo	Crestal	MTA	Initial treatment	Nonsurgical	57	Yes
14	3	Maxilla	Male	31	Large	Furcal	Bur	No	>1 mo	Crestal	MTA	Initial treatment	Apical surgery mb	112	Yes
8	1	Maxilla	Female	51	Large	Lateral	Post	No	>1 mo	Crestal	OptiBond/Tetric Flow/calcium sulfate	Initial treatment	Flap, GTR	27	No
3	3	Maxilla	Female	15	Large	Furcal	Bur	No	>1 mo	Crestal	MTA	Initial treatment	Nonsurgical	97	Yes
18	2	Mandible	Female	57	Small	Strip	Instrument	No	Immediately	Subcrestal	MTA	Initial treatment	Nonsurgical	12	Yes
14	3	Maxilla	Male	34	Medium	Lateral	Instrument	No	Unknown	Subcrestal	MTA	Retreatment	Nonsurgical	46	Yes
19	2	Mandible	Female	34	Large	Strip	Post	No	Unknown	Subcrestal	MTA	Retreatment	Nonsurgical	46	Yes
30	2	Mandible	Female	55	Large	Lateral	Instrument	No	Unknown	Subcrestal	MTA	Retreatment	Nonsurgical	98	Yes
29	1	Mandible	Male	52	Large	Lateral	Bur	No	Unknown	Crestal	Geristore	Retreatment	Nonsurgical	37	No
19	2	Mandible	Male	25	Large	Furcal	Bur	No	Unknown	Crestal	MTA/Biomed	Initial treatment	Nonsurgical	20	No
2	3	Maxilla	Female	23	Medium	Lateral	Post	No	Unknown	Subcrestal	MTA	Retreatment	Nonsurgical	12	Yes
11	1	Maxilla	Female	54	Medium	Lateral	Post	No	Unknown	Crestal	MTA	Retreatment	Nonsurgical	8	Yes
19	2	Mandible	Male	38	Large	Strip	Instrument	No	>1 mo	Crestal	MTA	Retreatment	Nonsurgical	9	No
30	2	Mandible	Female	56	Large	Furcal	Post	No	Unknown	Crestal	MTA	Retreatment	Nonsurgical	10	Yes
7	1	Maxilla	Female	36	Large	Lateral	Interior resorption	No	>1 mo	Subcrestal	MTA/calcium sulfate	Retreatment	Nonsurgical	24	Yes
14	3	Maxilla	Female	51	Large	Furcal	Bur	No	<1 mo	Subcrestal	MTA	Initial treatment	Nonsurgical	6	Yes
30	2	Mandible	Female	42	Medium	Strip	Instument	No	Unknown	Subcrestal	Gutta-percha	Retreatment	Nonsurgical	107	Yes
19	2	Mandible	Female	29	Medium	Furcal	Bur	No	<1 mo	Crestal	Geristore	Initial treatment	Nonsurgical	16	Yes

db, distobuccal; GTR, guided tissue regeneration; mb, mesiobuccal.

with loss of mineral, score 4: radiolucency at the site of perforation, and score 5: radiolucency with elements indicating expansion

Successful outcomes were defined as follows: no indication of apical periodontitis (PAI ≤2), no radiolucency adjacent to the perforation site (RPI ≤2), no continuing root resorption, no clinical signs and symptoms, and no loss of function.

This retrospective study was conducted in full accordance with ethical principles (World Medical Association Declaration of Helsinki, version VI, 2002). All 70 patients provided informed consent for endodontic treatment, and the 50 recall patients consented to the potential use of the outcome data for publication. Because of the retrospective study design and the anonymous nature of the data, no review by the local ethics committee was required.

Statistical Analysis

Statistical analysis was performed using SPSS 19.0 (IBM Corp, Armonk, NY). The level of significance was set at 0.05. The median, first and third quartile, maximum and minimum, and relative and absolute frequencies were calculated for descriptive analysis. No adjustment for multiple testing was made. The Fisher's exact and chi-square tests were performed to investigate the effect of potential outcome predictors (Table 2).

Results

Radiographic Findings

There was a high level of agreement between the 2 investigators. The interexaminer reliability ranged from κ = 0.71–0.83, and the intraexaminer agreement ranged from κ = 0.77–0.84, each indicating substantial agreement.

Clinical Findings

Forty-seven of 50 teeth had no clinical symptoms and were rated "functional" (94%). The statistical evaluation identified significant differences for the location of the perforation, preoperative radiographic coronal status, and sex (Table 2). When combining radiographic and clinical findings, 45 of 50 teeth (90%) were rated as "success." Figures 1-9 show 9 clinical cases.

Failures

Failure 1: Failure became evident at the 2-year recall. The treated tooth was graded as a PAI score of 1, and an RPI score of 4. Periodontal probing at the perforation site was 9 mm in combination with vertical bone loss and percussion sensitivity of 2. The tooth was scheduled for extraction after this recall examination.

Failure 2: The 4-year recall was graded as a PAI of 1 and an RPI of 2. Probing depths were within normal limits. The tooth was asymptomatic and restored with a porcelain fused to metal (PFM) crown and a cast post and core. After 6 years, the tooth was extracted because of a complicated crown fracture and replaced by an implant.

Failure 3: At the 2-year recall, the tooth exhibited a PAI score of 2, an RPI score of 2, and was asymptomatic. At the 5-year recall, the PAI (mesial root) increased to 4 and the RPI to 3. The tooth was still asymptomatic and functional.

Failure 4: The 3-year recall was graded with PAI and RPI scores of 1, probing depth at the buccal perforation site of 6 mm, mobility of 2, and swelling caused by a periodontal abscess. The tooth was extracted.

Failure 5: The 2-year recall showed furcal breakdown at the perforation site (RPI score of 5), a PAI score of 2, mobility of 1, furcation involvement of 3, palpation, and percussion sensitivity of 2. The tooth also exhibited a sinus tract and was extracted after the recall examination.

Discussion

Retrospective studies, by definition, are not randomized, and teeth thought to have a poor prognosis are generally excluded from treatment in a private practice. The sample size of 50 teeth is larger than in other published studies on this topic, which range from 4–26 teeth (18–20). The inclusion of patients from 6 practices could be viewed as a weakness because of a lack of standardization but may also be viewed as a strength because it is somewhat representative of the variation in the endodontic community (eg, freshly mixed calcium hydroxide by 1 specialist; the other specialists used UltraCal XS instead). However, because of the fact that the type of calcium hydroxide did not affect the outcome (P = .158), this variation in terms of treatment protocols was negligible. Patients were treated in different countries on different continents. Consequently, the same clinicians performed the clinical procedures and recall evaluations, which can be seen as another weakness of this study (24). No interobserver agreement of clinical testing is available. Two independent, calibrated examiners evaluated all radiographs after recalls.

The recalls ranged from 6–116 months (median = 37 months), which represents an acceptable recall period according to Friedman (24), but is shorter than ideal. According to Ng et al (17), the majority of periapical radiolucencies are expected to heal within 2 years. Furthermore, Ørstavik (25) mentioned that signs of healing in cases with chronic apical periodontitis were visible in at least 89% of all healing roots within 1 year. Ideally, the outcome of perforation repair, or any clinical procedure, should be based on longer follow-up periods.

In this study, 2 failures were identified at recalls of less than 2 years, and 3 failures were identified at later recalls. Thirty of the 50 treatment cases (60%) had an observation period of >24 months, and 27 of these cases were rated as "success" and 3 as "failure." Twenty treatments were observed for 2 years or less (40%). Comparing the failures of "longer-term" and "shorter-term" observation groups, we found a relation of 60:40 (the same proportional failure distribution, 3:2). However, it is possible that there were failing cases that have not yet been identified at the initial recalls and will result in future failures. For example, failure 3 was rated a success at the 2-year recall but a radiographic failure at the 5-year recall. However, it should be pointed out that failure 3 was still functional and asymptomatic at 5 years. Nonetheless, the 90% success rate must be viewed with caution, and additional failures are likely to occur over time.

Perforation repair does not occur frequently, which makes it a difficult topic to study. A retrospective study by Tsesis et al (3) investigated a total of 5,048 root canal–treated teeth and identified 116 root perforations (2.3%). Pathological changes were found in 81 teeth with perforations (1.6%). A prospective study by Touré et al (26) studied the extraction of endodontically treated teeth and identified iatrogenic perforations as the reason for extraction in 4.2% of the cases. Both studies show that it is challenging to collect enough perforation cases to provide adequate statistical power for a study. Long-term recalls are difficult for a variety of reasons, including the fact that the willingness of the patients to present for recalls decreases with time. In this study, 40% of the recalls were 4 years or longer.

The PAI scoring system was used in this study, which has been accepted as a reproducible method to assess periapical status (23, 24). There is currently no scoring system available that allows the evaluation of perforation repairs. Thus, the authors devised a new scoring system, the RPI, which was modeled after the PAI. The RPI offers 5 potential scores of the bone condition to the perforation site

TABLE 2. Outcome Distribution Across Preoperative, Intraoperative, and Postoperative Variables

	Teeth		Success				
Variable	*n*	%	*n*	%	Odds ratio	95% CI (LCI/UCI)	*P* value
Preoperative variables							
Age							1.00*
≤45 y	24	48	22	92	1.04	0.86/1.25	
>45 y	26	52	23	89	1		
Sex of patient							0.04*
Female	32	65	32	97	1.27	0.97/1.66	
Male	17	35	13	77	1		
Number of roots							0.65*
1	16	32	14	81	1		
≥2	34	68	31	91	1.04	0.84/1.29	
Tooth type							1.00*
Anterior	12	24	11	92	1.03	0.84/1.25	
Posterior	38	76	34	90	1		
Tooth location							0.35*
Maxilla	24	48	23	96	1.13	0.94/1.36	
Mandible	26	52	22	85	1		
Localization of perforation							0.03†
Supracrestal	1	2	1	100			
Crestal	22	44	17	77			
Subcrestal	27	54	27	100			
Perforation type							0.79†
Furcal	18	36	16	89			
Root, lateral	26	52	24	92			
Strip	6	12	5	83			
Size of perforation							0.13†
Small (≤1 mm)	4	14	4	100			
Middle (1–3 mm)	17	34	17	100			
Large (>3 mm)	29	58	24	83			
Cause of perforation							0.91†
Bur	19	38	16	84			
Instrument	16	32	15	94			
Post/screw	11	22	10	91			
Internal resorption	2	4	2	100			
External resorption	2	4	2	100			
Prior repair							1.00*
Yes	1	2	1	100	1.11	1.01/1.22	
No	49	98	44	90	1		
Sinus tract							1.00*
Absent	46	92	41	89	1		
Present	4	8	4	100	1.12	1.01/1.24	
Apical periodontitis (PAI score ≥3)							0.60*
Absent	22	42	17	81	1		
Present	28	58	26	93	1.08	0.89/1.33	
Status at perforation site (RPI ≥3)							1.00*‡
No inflammation	8	16	7	88	1		
Inflammation	36	72	32	89	1.02	0.76/1.35	
Not detectable/visible	6	12	6	100			
Duration of perforation							0.91†
≤1 d	4	8	4	100			
>1 d–31 d	8	16	7	88			
>1 mo	17	34	15	88			
Unknown	21	42	19	90			
Type of treatment							0.65*
Initial treatment	23	46	20	87	1		
Retreatment	27	54	25	93	1.07	0.88/1.29	
Radiographic coronal status							0.02†
Score 1	34	68	32	94			
Score 2	7	14	4	57			
Score 3	2	4	2	100			
Length of root filling							0.31†
Adequate root filling	13	26	11	85			
Underfilling	12	24	12	100			
Overfilling	2	4	2	100			
No root filling	23	46	20	87			
Homogeneity of root filling							0.66†
Homogeneous filling	22	44	20	91			
Inhomogeneous filling	5	10	5	100			
No root filling	23	46	20	87			
Root filling score							0.87†

(*Continued*)

TABLE 2. (*Continued*)

Variable	Teeth n	Teeth %	Success n	Success %	Odds ratio	95% CI (LCI/UCI)	*P* value
Score 1	3	6	3	100			
Score 2	4	8	4	100			
Score 3	2	4	2	67			
Score 4	7	14	6	86			
Score 5	11	22	10	91			
No root filling	23	46	20	87			
Intraoperative variables							
Medical dressing							1.00*
Calcium hydroxide	47	94	42	89	1		
Ledermix	3	6	3	100	1.12	1.01/1.24	
Repair material							0.60*
MTA	37	74	34	92	1.09	0.85/1.40	
Other	13	26	11	85	1		
Surgical intervention							0.42*
No	45	90	41	91	1.14	0.73/1.78	
Yes	5	10	4	80	1		
Postoperative variables							
Apical periodontitis (PAI score ≥3)							0.002†
Absent	47	94	44	94			
Present	3	6	0	0			
Status at perforation site (RPI ≥3)							0.000*
No inflammation	46	92	44	96			
Inflammation	4	8	0	0			
Not detectable/visible	0	0	0	0			
Radiographic coronal status§							0.585†
Score 1	46	92	40	87			
Score 2	2	4	2	100			
Score 3	0	0	0	0			
Length of root filling							0.091†
Adequate root filling	48	96	43	90			
Underfilling	0	0	0	0			
Overfilling	2	4	1	50			
No root filling	0	0	0	0			
Homogeneity of root filling							0.509†
Homogeneous filling	47	94	41	87			
Inhomogeneous filling	3	6	0	0			
No root filling	0	0	0	0			
Coronal leakage							0.02*
No	47	94	44	94	2.81	0.57/13.94	
Yes	3	6	1	33	1		
Restoration type							1.00*
Direct composite filling	9	18	8	89	1		
Indirect restoration	41	82	37	90	1.02	0.79/1.31	
Post insertion							1.00*
Yes	14	28	13	93	1.05	0.87/1.26	
No	36	72	32	88.9	1		

CI, confidence interval; LCI, lower confidence interval; PAI, perapical index; RPI, root perforation index; UCI, upper confidence interval.

*Fisher's exact test.

†Chi-square test.

‡Statistics calculated for 44 cases.

§No information available for 2 cases.

as interpreted from the radiographs. Mente et al (18) reported problems in applying the PAI scoring system to a perforation site. They used the PAI for rating the perforation site and classified a case as healed if all radiographic and clinical findings were normal (eg, PAI score ≤2). In this study, we rated the apex and perforation site separately with slightly different criteria. This allowed more precise evaluation if the failure was based on the perforation repair or other factors.

In healing studies, the standardization and quality of the radiographs are very important and can affect the outcome greatly. In this study, all radiographs were digital, were taken by experienced operators, and were of diagnostic quality. Only patients with adequate radiographs were included in this study. The lack of standardization of the radiographs was a weakness of this study. Angulation affects the visualization, size, and density of radiolucent areas. Although periapical radiographs still represent the standard of care (27), the reliability of this method has been questioned in recent years (28, 29). The treatment outcome in this study may have been less favorable if cone-beam computed tomographic imaging had been used as the standard. However, clinical radiography must follow the ALARA (as low as reasonably achievable) principle, so it is hard to justify the routine use of the cone-beam computed tomographic device at recall appointments. For this study, the assessment of the RPI score using conventional radiographs was considered to be suitable for the investigation of healing at the perforation site.

MTA has been described as the material of choice for intra-alveolar perforation repairs (20) and was used in the majority of treated cases as the repair material in the present study (37/50). Other materials used were gutta-percha, glass ionomer cement, or composite. The

Figure 1. Case 1. (*A*) A preoperative radiograph of tooth #4 showing a lateral midroot perforation and periapical radiolucency. (*B*) The canal system was obturated apically with warm gutta-percha, the perforation sealed with MTA, and the post space prepared. (*C*) The 7-year recall shows no evidence of endodontic disease. The patient underwent orthodontic treatment; the tooth was restored with a cast post and core and a PFM crown.

decision was dependent on the clinical situation. If the perforation was small, in some cases gutta-percha was used for conventional obturation. There was no difference in the outcome between MTA and the other materials in this study (92% vs 85% respectively, P = .60), but our sample size was too small to draw firm conclusions.

Our overall success rate was 90%, which was similar to the study of Mente et al (18), who detected a healed rate of 86% in perforations exclusively repaired with MTA. Based on the data of this study and other articles, MTA is a suitable repair material for intraosseous perforations (13, 14, 16, 18) with no aesthetic issues (15).

Most of the perforation repairs (90%) were performed nonsurgically. For large perforations in which overfill was a concern (30), MTA was used with an absorbable matrix (collagen, calcium and sulfate); this technique was previously described by several authors (12, 19, 31).

The location of the perforation was found to be a significant prognostic factor for success (P = .03). Each of the failed cases exhibited perforations at or close to the level of the osseous crest (Table 2). This was probably caused by the proximity to the epithelial attachment, with the increased likelihood of bacterial contamination during or after treatment. This finding was consistent with the Toronto study (1, 17)

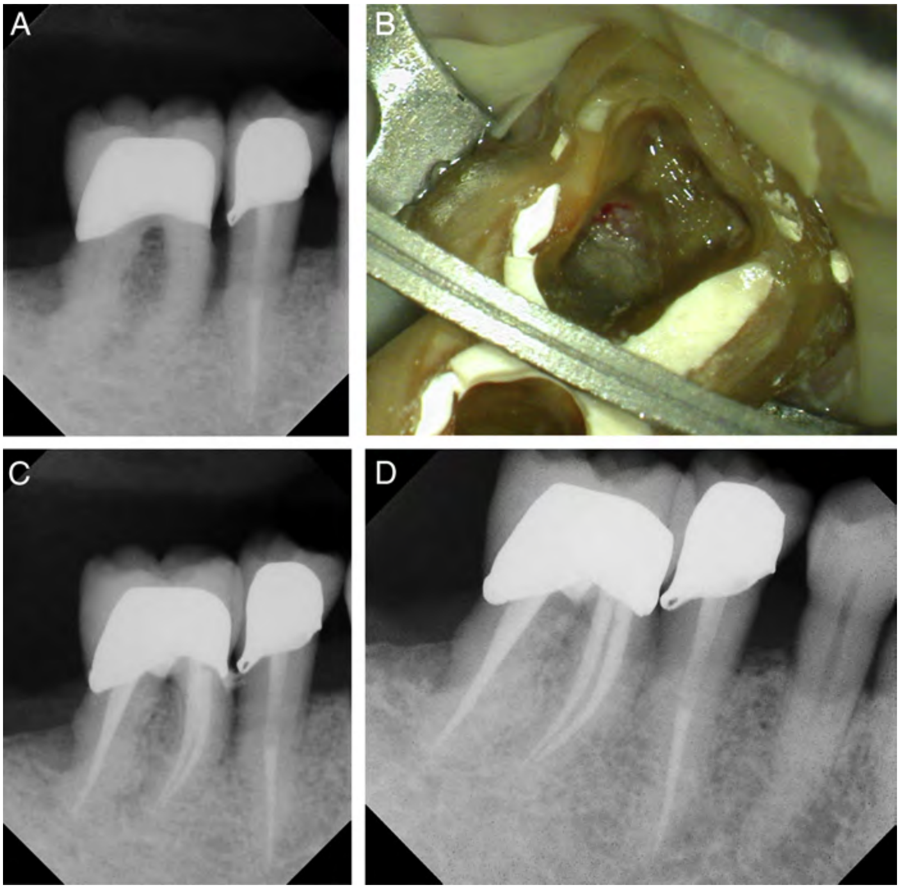

Figure 2. Case 2. (*A*) A preoperative radiograph of tooth #30. The patient presented with pulp necrosis and acute apical periodontitis. (*B*) A clinical photograph showing a perforation in the furcation area. (*C*) A postoperative radiograph after obturation of the root canal system and perforation repair with calcium sulfate and composite. (*D*) At the 4.5-year recall, the radiograph showed no evidence of endodontic disease.

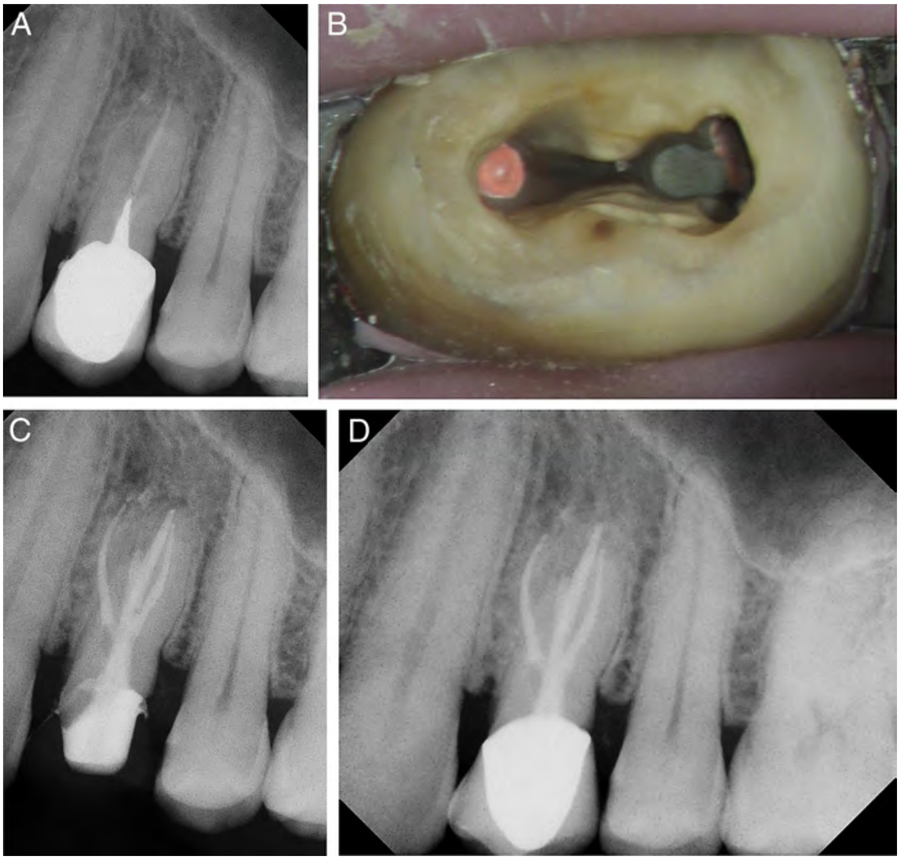

Figure 3. Case 3. (*A*) A preoperative radiograph of tooth #12 showed periapical radiolucency and missed canal systems. (*B*) After disassembly, a furcal perforation of the buccal roots was visualized and sealed with MTA. The canal system was retreated and obturated with warm gutta-percha. (*C*) A postoperative radiograph. (*D*) At the 1-year recall, the tooth was asymptomatic, functional, and restored with a PFM crown. The radiograph showed no evidence of endodontic disease.

and a study by Ng et al (32). A second factor was sex. Perforation repairs in female patients had a higher success rate than repairs in male patients (P = .04). These findings are in contrast to other studies (1,16–18, 32) that did not detect significant differences between male and female patients. A third factor was initial radiographic coronal status. Restorations that were rated “unacceptable” before intervention were associated with a higher failure rate (P = .02). This could be explained by the potential bacterial contamination prior, during, or after endodontic treatment. The quality of the coronal restoration is reported to be of major importance for endodontic success (33). This was in agreement with the findings in a study by Ng et al (32) in which good quality coronal restorations increased the odds of success by 11-fold.

Contrary to a study by Fuss and Trope (10), the size of the perforation did not influence the treatment success and healing in this study or the study by Mente et al (18). No significant difference was observed in this study between the initial treatment and retreatment (initial treatment: success = 87%, retreatment: success: =

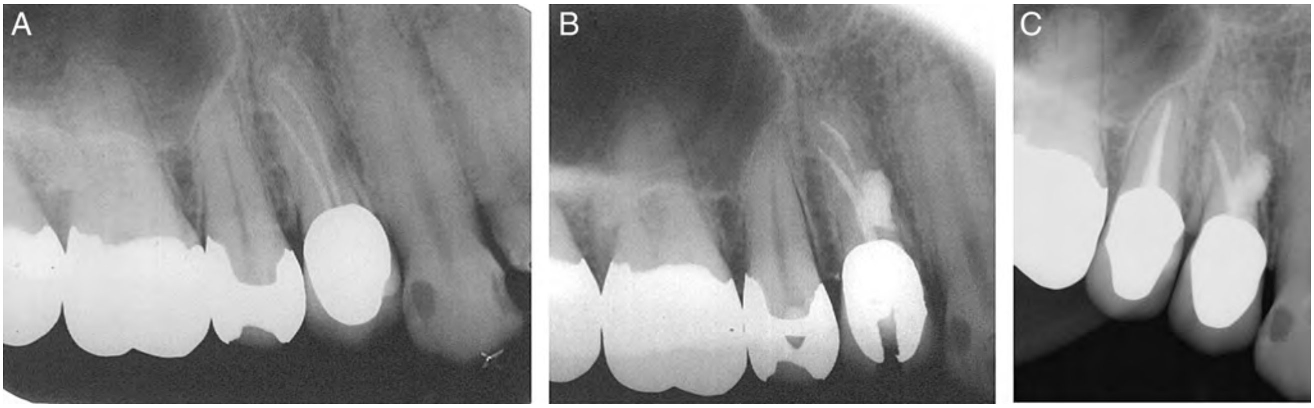

Figure 4. Case 4. (*A*) A preoperative radiograph of tooth #5. (*B*) After disassembly, a large lateral midroot perforation was visualized. A postoperative radiograph showing the perforation sealed with MTA and the root canal system retreated and obturated with warm gutta-percha. (*C*) A radiograph taken 5 years after perforation repair. The tooth was asymptomatic, functional, and restored with a PFM crown.

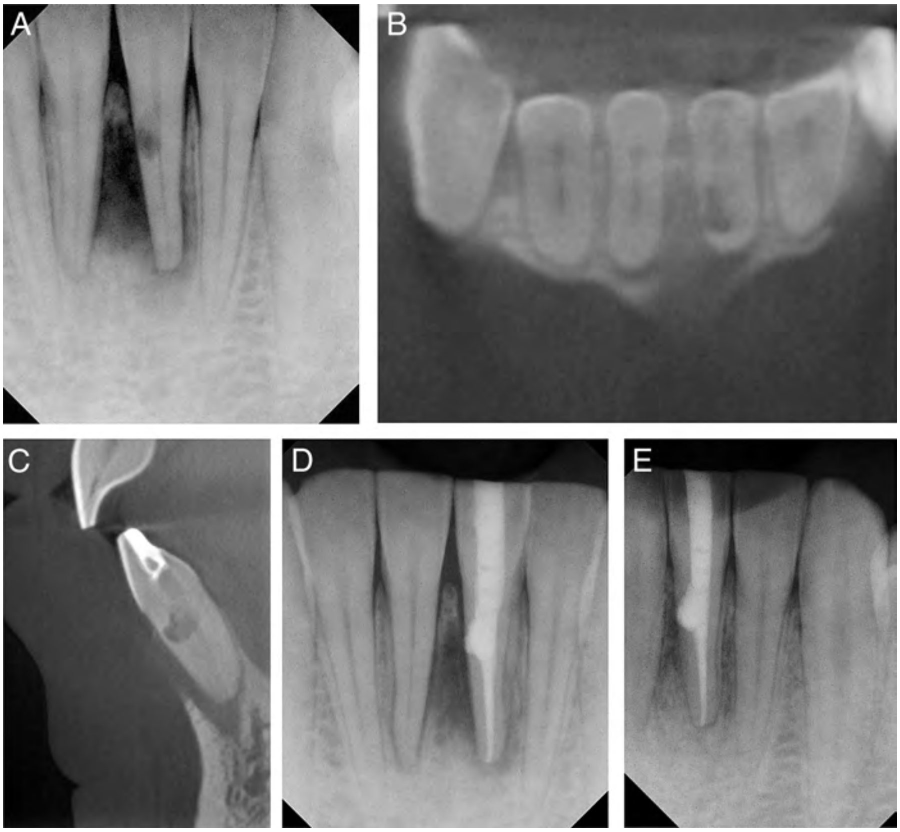

Figure 5. Case 5. (*A*) A preoperative radiograph of tooth #24 showing an external root resorption and periapical and lateral radiolucencies. The patient presented with pulp necrosis and class 2 mobility of tooth #24. (*B*) Cone-beam computed tomographic imaging visualizing the horizontal dimension of the resorption and involvement of the buccal cortical plate. (*C*) Cone-beam computed tomographic sagittal slice. (*D*) A postoperative radiograph after cleaning, shaping, and obturation of the root canal system with warm gutta-percha; perforation repair with MTA; and an adhesive buildup with composite. (*E*) A 9-month recall radiograph with evidence of healing; the tooth was functional and asymptomatic.

93%; P = .65), the presence or absence of preoperative apical periodontitis (P = .60), and the periodontal status at the perforation site (P = 1.00). None of these factors affected the success of endodontic treatment or perforation repair. These observations are in contrast to the findings in the study of Farzaneh et al (1) who reported the healed rate in retreatment cases was significantly affected by the presence of apical periodontitis (absent = 97%, present = 78%) and the presence of perforation (absent = 89%, present = 42%)

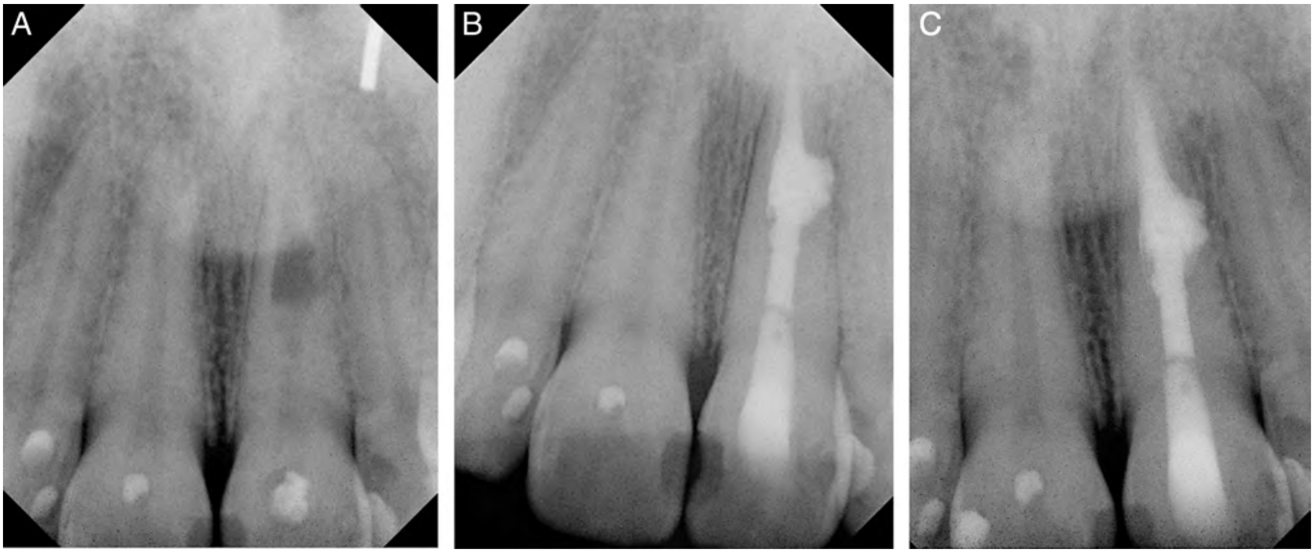

Figure 6. Case 6. (*A*) A preoperative radiograph of tooth #9 with a perforating internal resorption at the midroot level. (*B*) A postoperative radiograph after obturation of the resorptive defect and the apical third of the root canal with MTA, backpacking with warm gutta-percha, and adhesive buildup with composite. (*C*) At the 4.5-year recall, the radiograph showed no evidence of endodontic disease.

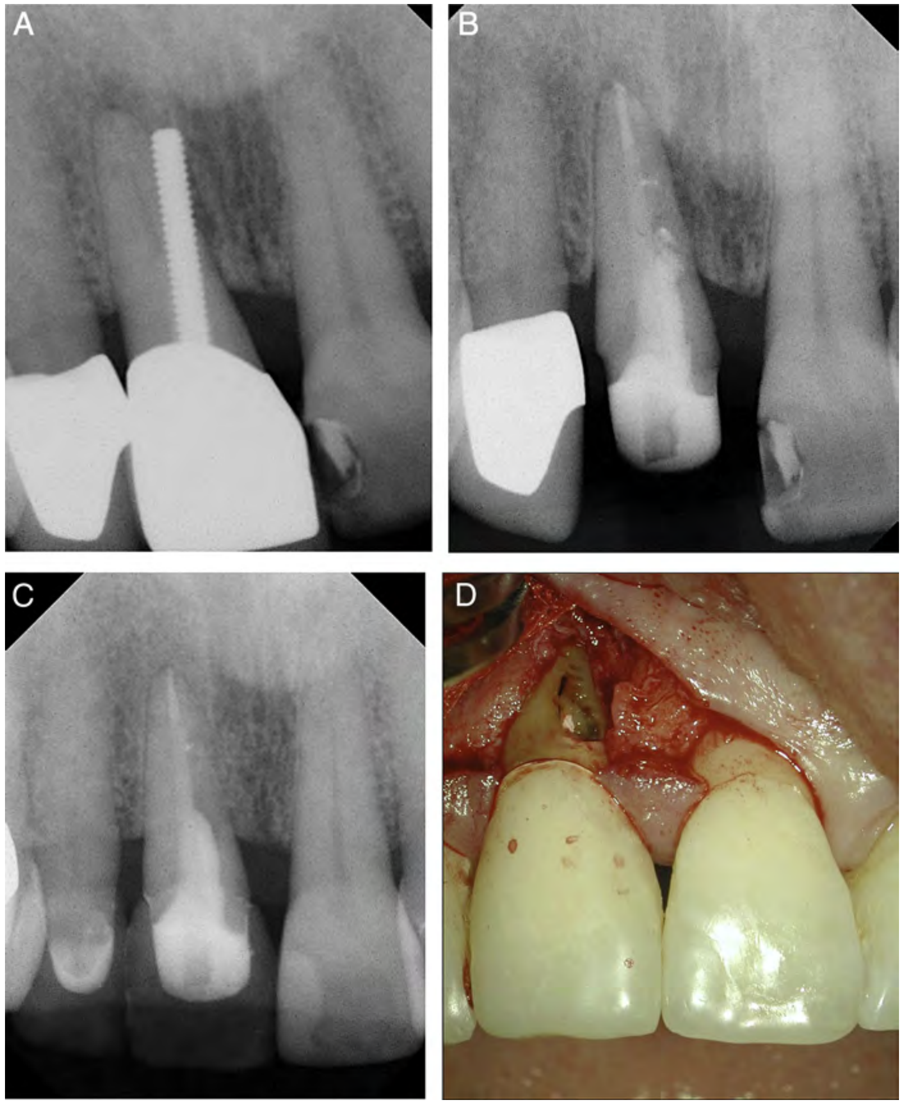

Figure 7. Case 7. (*A*) A preoperative radiograph of tooth #8 with post perforation of the root. (*B*) An intraoperative radiograph after post removal, sealing of the perforation site with calcium sulfate, obturation of the root canal system with warm gutta-percha, and adhesive buildup with a quartz fiber post and composite. (*C*) A clinical photograph of the perforation site before sealing it with composite in combination with guided bone regeneration. (*D*) A 2-year recall radiograph. The tooth was functional and asymptomatic; the radiograph showed no evidence of endodontic disease. After 3 years, the tooth developed a periodontal abscess at the buccal site and was extracted (failure 4).

(1). However, it must be considered that Farzaneh et al only investigated 12 perforation cases.

Comparing surgical versus nonsurgical treatment, there was no significant difference in terms of the success rate (P = .60). However, the number of combined cases with nonsurgical and surgical intervention was small (5 cases).

The data from this study show that perforations can be repaired successfully with meticulous cleaning and shaping, adequate

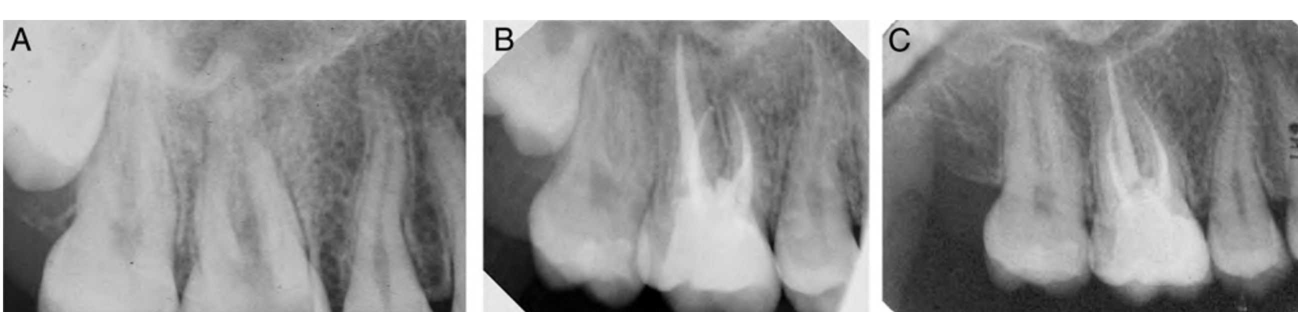

Figure 8. Case 8. (*A*) A preoperative radiograph of tooth #3 with a large furcal perforation and periapical radiolucencies. The tooth also exhibited a sinus tract on the palatal site. (*B*) A postoperative radiograph showing the perforation sealed with MTA, the root canal system obturated with warm gutta-percha, and an adhesive buildup of the access cavity. (*C*) At the 8-year recall, the radiograph showed no evidence of endodontic disease.

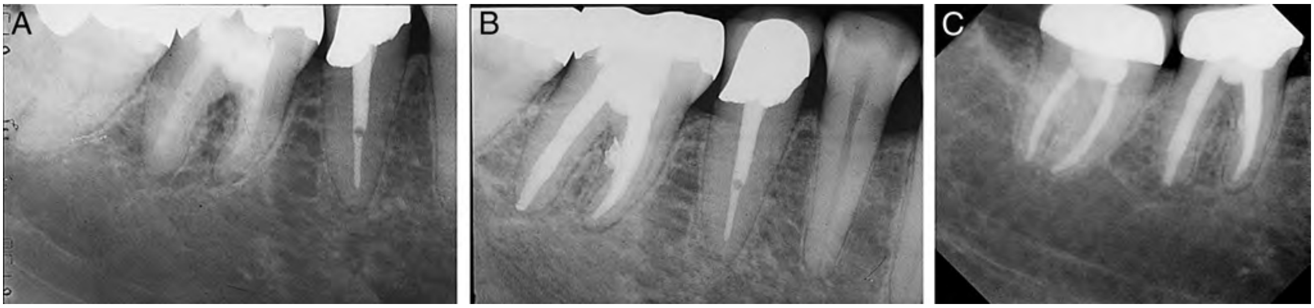

Figure 9. Case 9. (*A*) A preoperative radiograph of tooth #30 exhibiting an acute apical periodontitis. (*B*) A postoperative radiograph showing a strip perforation in the middle third of the mesial root. It was sealed with warm gutta-percha and Kerr Culp Canal Sealer (Sybron Endo, Orange, CA). (*C*) At the 9-year recall, the radiograph showed no evidence of endodontic disease. The tooth was asymptomatic and functional.

disinfection, proper handling of the repair material, and adequate obturation followed by adequate coronal restoration. However, proper treatment planning includes other important considerations (34, 35). Restorative factors such as remaining tooth structure, ferrule height and width, functional loads, aesthetic considerations, periodontal status, the conditions of the adjacent teeth and the entire dentition, and the age and general health issues of the patient must be included in the decision process. Finally, the projected quality of the final restorative treatment is a major consideration in treatment planning.

Conclusions

This retrospective study of 50 cases produced a success rate of 90% from a collection of perforation repairs performed in 6 different practices. Within the limits of this investigation, the location of the perforation, the coronal status of the restoration, and the sex of the patient were factors that significantly affected the outcome. However, the high success rate of the perforation repairs must be viewed with caution because 20 of the cases were recalled for periods of less than 2 years and some less than 1 year and they are still subject to failure at subsequent recalls. Long-term studies, ideally prospective, are needed to adequately address the question of success and failure of perforation repairs. This study was a step in that direction.

Acknowledgments

The authors would like to express their gratitude to the following endodontic specialists for their participation in the present study: Dr Raphael Bellamy, Dr Francesco Maggiore, Dr Sashi Nallapati, Dr Terrell F. Pannkuk, and Dr Marga Ree. Special thanks to Dr Rick Schwartz for his valuable comments regarding the finishing of this manuscript and the proofreading of this article.

The authors deny any conflicts of interest related to this study.

References

1. Farzaneh M, Abitbol S, Friedman S. Treatment outcome in endodontics: the Toronto study. Phases I and II: orthograde retreatment. J Endod 2004;30:627–33.
2. Kvinnsland I, Oswald RJ, Halse A, et al. A clinical and roentgenological study of 55 cases of root perforation. Int Endod J 1989;22:75–84.
3. Tsesis I, Rosenberg E, Faivishevsky V, et al. Prevalence and associated periodontal status of teeth with root perforation: a retrospective study of 2,002 patients' medical records. J Endod 2010;36:797–800.
4. Clauder T, Shin SJ. Repair of perforations with MTA: clinical applications and mechanisms of action. Endod Top 2006;15:32–55.
5. Schilder H. Cleaning and shaping the root canal. Dent Clin North Am 1974;18: 269–96.
6. Ruddle C. Nonsurgical endodontic retreatment. In: Cohen S, Burns RC, eds. *Pathways of the Pulp*, 10th ed. St Louis: Mosby; 2011.
7. Eleftheriadis GI, Lambrianidis TP. Technical quality of root canal treatment and detection of iatrogenic errors in an undergraduate dental clinic. Int Endod J 2005;38:725–34.
8. Lofthag-Hansen S, Huumonen S, Gröndahl K, et al. Limited cone-beam CT and intraoral radiography for the diagnosis of periapical pathology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103:114–9.
9. Tsesis I, Fuss Z. Diagnosis and treatment of accidental root perforations. Endod Top 2006;13:95–107.
10. Fuss Z, Trope M. Root perforations: classification and treatment choices based on prognostic factors. Endod Dent Traumatol 1996;12:255–64.
11. Zairi A, Lambrianidis T, Pantelidou O, et al. Periradicular tissue responses to biologically active molecules or MTA when applied in furcal perforation of dogs' teeth. Int J Dent 2012;2012:257832.
12. Pitt Ford TR, Torabinejad M, McKendry DJ, et al. Use of mineral trioxide aggregate for repair of furcal perforations. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1995;79:756–63.
13. Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review—part I: chemical, physical, and antibacterial properties. J Endod 2010;36: 16–27.
14. Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review—part III: clinical applications, drawbacks, and mechanism of action. J Endod 2010;36:400–13.
15. Krastl G, Allgayer N, Lenherr P, et al. Tooth discoloration induced by endodontic materials: a literature review. Dent Traumatol 2013;29:2–7.
16. De Chevigny C, Dao TT, Basrani BR, et al. Treatment outcome in endodontics: the Toronto study—phases 3 and 4: orthograde retreatment. J Endod 2008;34:131–7.
17. Ng YL, Mann V, Gulabivala K. A prospective study of the factors affecting outcomes of nonsurgical root canal treatment: part 1: periapical health. Int Endod J 2011;44: 583–609.
18. Mente J, Hage N, Pfefferle T, et al. Treatment outcome of mineral trioxide aggregate: repair of root perforations. J Endod 2010;36:208–13.
19. Main C, Mirzayan N, Shabahang S, et al. Repair of root perforations using mineral trioxide aggregate: a long-term study. J Endod 2004;30:80–3.
20. Ree M, Schwartz R. Management of perforations: four cases from two private practices with medium- to long-term recalls. J Endod 2012;38:1422–7.
21. Available at: http://www.tulsadentalspecialties.com/Libraries/Tab_Content_Accessories/TCC11110-10E_MTA_Del_Tip.sflb.ashx. Accessed July 4, 2013.
22. Hommez GM, Coppens CR, De Moor RJ. Periapical health related to the quality of coronal restorations and root fillings. Int Endod J 2002;35:680–9.
23. Ørstavik D, Kerekes K, Eriksen HM. The periapical index: a scoring system for radiographic assessment of apical periodontitis. Endod Dent Traumatol 1986;2:20–34.
24. Friedman S. Expected outcomes in the prevention and treatment of apical periodontitis. In: Ørstavik D, Pitt Ford T, eds. *Essential Endodontology: Prevention and Treatment of Apical Periodontitis*, 2nd ed. Oxford: Blackwell Munksgaard Ltd; 2008:408–69.
25. Ørstavik D. Time-course and risk analyses of the development and healing of chronic apical periodontitis in man. Int Endod J 1996;29:150–5.
26. Touré B, Faye B, Kane AW, et al. Analysis of reasons for extraction of endodontically treated teeth: a prospective study. J Endod 2011;37:1512–5.
27. Fristad I, Molven O, Halse A. Nonsurgically retreated root filled teeth—radiographic findings after 20-27 years. Int Endod J 2004;37:12–8.
28. Wu MK, Shemesh H, Wesselink PR. Limitations of previously published syste-matic reviews evaluating the outcome of endodontic treatment. Int Endod J 2009;42:656–66.
29. Estrela C, Bueno MR, Leles CR, et al. Accuracy of cone beam computed tomography and panoramic and periapical radiography for detection of apical periodontitis. J Endod 2008;34:273–9.

30. Rafter M, Baker M, Alves M, et al. Evaluation of healing with use of an internal matrix to repair furcation perforations. Int Endod J 2002;35:775–83.
31. Pace R, Giuliani V, Pagavino G. Mineral trioxide aggregate as repair material for furcal perforation: case series. J Endod 2008;34:1130–3.
32. Ng YL, Mann V, Gulabivala K. A prospective study of the factors affecting outcomes of non-surgical root canal treatment: part 2: tooth survival. Int Endod J 2011;44:610–25.
33. Balto K. Root-filled teeth with adequate restorations and root canal treatment have better treatment outcomes. Evid Based Dent 2011;12:72–3.
34. Zitzmann NU, Krastl G, Hecker H, et al. Endodontics or implants? A review of decisive criteria and guidelines for single tooth restorations and full arch reconstructions. Int Endod J 2009;42:757–74.
35. Ree M, Schwartz R. The endo-restorative interface: current concepts. Dent Clin North Am 2010;54:345–74.