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Title Page

Targeted Endodontic Microsurgery: A Retrospective Outcomes Assessment of 24 Cases

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Abstract

Introduction: Targeted Endodontic Microsurgery (TEMS) replaces freehand carbide or diamond bur osteotomy and root end resection with a guided approach using an end-cutting trephine bur rotated within a guide tube. TEMS departs from traditional endodontic microsurgery (EMS) in osteotomy size, control of resection level and bevel, surgical time and resection method, yet the impact of these departures upon clinical outcomes has yet to be assessed. The aim of this study is to assess clinical outcomes of TEMS surgeries at least one year after treatment.

Methods: Potential cases were retrospectively identified from a secure database of all patients that received TEMS in the Air Force Postgraduate Dental School from June 2017 to May 2019 with a postsurgical follow-up exam at 1 year or beyond (23 patients with 24 teeth). Two board certified endodontists completed a calibration exercise prior to assessing radiographs. A retrospective outcomes assessment was conducted considering follow-up clinical and radiographic findings to assign 1 of 3 healing designations: *complete healing*, *reductive healing*, or *failure*.

Results: Combined clinical and radiographic data led to 20 designations of *complete healing*, 2 designations of *reductive healin*g and 2 *failures* (91.7% success rate). Considered alone, radiographic criteria for *complete healing* were met for 20 cases, *reductive healing* by 3 cases, and radiographic *failure* for 1 case.

Conclusions: This limited retrospective outcomes assessment is an early indication that TEMS-guided trephine bur root end resection leads to similar success as is established for freehand

carbide and diamond bur resection. Controlled clinical trials with long-term follow-up are warranted.

Key Words
3-dimensional printed; apical surgery; endodontic microsurgery; outcomes; surgical guide; targeted endodontic microsurgery; trephine

Statement of Clinical Relevance

Targeted endodontic microsurgery departs from traditional endodontic microsurgery in osteotomy size, control of resection level and bevel, surgical time and resection method. The impact of these departures on clinical outcomes is assessed in this study.

Introduction

Targeted endodontic microsurgery (TEMS) replaces freehand carbide or diamond bur osteotomy and root-end resection with a guided approach using an end-cutting trephine bur rotated within a guide tube (1). After trephine resection, root ends receive ultrasonic preparation and fill with a biocompatible material under the surgical operating microscope (2). TEMS customizes the osteotomy diameter and root-end resection level and bevel with a preoperative digital design that is transferred to the surgical field with a 3-dimensional printed surgical guide (3). In a mannequin simulation study, TEMS resulted in constricted osteotomies with more appropriate root-end resection level and bevel accomplished in significantly less time, as compared to freehand osteotomy and resection (4). Reduced surgical time and osteotomy size may result in better healing outcomes (2, 5). As new endodontic surgical techniques and armamentaria become available, it is important to assess the resulting clinical outcomes. TEMS departs from traditional endodontic microsurgery (EMS) in osteotomy size, control of resection level and bevel, surgical time, and resection method, but the impact of these departures on clinical outcomes has yet to be assessed.

Rud et al (6) proposed outcomes assessments at least 1 year after surgery by radiographically assigning cases to 1 of 4 categories: *complete healing, incomplete healing, uncertain healing,* or *unsatisfactory healing*. They also correlated radiographic designations with subjective and objective clinical findings. Subsequently, Molven et al (7) added an "observer strategy" to the radiographic criteria proposing systematic training using illustrations and radiographs before performing an individual outcomes assessment. After individual assessment, examiners viewed radiographs together resulting in a 94% agreement for radiographic healing designations. The principles of these 2 studies are widely applied to EMS outcomes assessments (8-13).

In a cone-beam computed tomography (CBCT)-based investigation, Curtis et al (14) adapted these principles to establish 3 outcome categories based on clinical and radiographic findings. *Complete healing* was defined as the absence of pain, the absence of percussion and palpation tenderness, no probing depths indicative of endodontic failure, and CBCT periapical radiolucency of 3.6 mm^3 or less. *Reductive healing* was defined as the absence of pain, the absence of percussion and palpation tenderness, no probing depths indicative of endodontic failure, and a CBCT periapical radiolucency that had reduced in volume but was greater than 3.6 mm^3. *Failure* was defined by the presence of pain, percussion or palpation tenderness, probing depths indicative of endodontic failure, or an unchanged or enlarged CBCT periapical lesion volume. This classification eliminates possible confusion that can arise from the Rud et al (6) categories of *incomplete healing* and *uncertain healing*, both of which allow for a reduction in radiolucency without complete resolution.

The aim of this study is to assess outcomes of TEMS at least 1 year after treatment, adapting the Curtis et al (14) CBCT-based assessment to a periapical (PA) radiograph-based outcomes assessment.

Materials and Methods

The 59th Medical Wing Institutional Review Board approved this study.

TEMS Clinical Technique

Endodontic faculty and residents performed surgical procedures using the TEMS technique described previously (1). Immediate postsurgical and 1-year postsurgical PA radiographs were taken using an external positioning device and a size 2 sensor (RGV 6100; Kodak, Rochester, NY). An x-ray machine (Planmeca Intra, Helsinki, Finland) exposed the sensors with kVp, mA, and exposure time, adjusted for patient size and location in the dental arch. After full-thickness flap reflection, clinicians seated a surgical guide and tapped a guided trephine bur through bone and root end at 900-1000 rpm with copious irrigation. Surgeons elevated the tissue core of the bone and root end and then (in all but 2 cases) ultrasonically prepared and filled the root end with EndoSequence Root Repair Material (Brasseler USA, Savanah, Georgia) under the surgical operating microscope. In 2 cases, presurgical orthograde-placed white ProRoot MTA (Dentsply, Tulsa, OK) was deemed serviceable, and no root end preparation or fill was performed. All root ends were stained with methylene blue dye before final inspection.

Clinical Data Collection and Interpretation

Potential cases were retrospectively identified from a secure database of all patients who received TEMS in the Air Force Postgraduate Dental School, Lackland AFB, TX from June 2017-May 2019. All initial or resurgery TEMS cases with a 1-year or greater postsurgical clinical and radiographic examination were included. The following intraoperative and recall data were entered into a secure database: American Association of Anesthesiologists (ASA) classification, age, sex, tooth type, grafting materials (if used), root-end filling type, subjective report at recall, mobility, probing depths, presence of a sinus tract and percussion and palpation responses.

Outcomes Designations

Complete healing was defined as the absence of pain, absence of percussion and palpation tenderness, no probing depths indicative of endodontic failure, and complete resolution of immediate postsurgical radiolucency with periodontal ligament width up to twice that of non-involved parts of the root (6). *Reductive healing* was defined as the absence of pain; the absence of percussion and palpation tenderness; no narrow, deep probing depth characteristic of endodontic failure, and incomplete reduction of immediate postsurgical radiolucency. *Complete healing* and *reductive healing* were considered successful outcomes. *Failure* was defined as the presence of pain, percussion or palpation tenderness, probing depths characteristic of endodontic failure, and/or a radiolucency of the same size or enlarged over the immediate postsurgical size.

Examiner Calibration and Radiographic Assessment

Two board-certified endodontists completed a calibration exercise that included a detailed review of the radiographic outcomes criteria described by Rud et al (6) and the modified outcomes categories adapted by Curtis et al (14). The raters then graded a series of 40 paired immediate postsurgical and recall radiographs that were unrelated to the study sample using radiographic appearance alone to assign 1 of the outcome designations (*complete healing*, *reductive healing* or *failure*). Next, deidentified immediate postsurgical and follow-up radiographs of each TEMS case were assessed by individual examiners to assign 1 of the 3 outcome assessment designations based on radiographic appearance alone. When individual assessments were not in agreement, examiners viewed and discussed the radiographs together in an attempt to achieve consensus. This process of individual and consensus assessment was repeated 7 days later.

Final Outcomes Assessment

Radiographic classifications were combined with clinical data (pain, percussion or palpation tenderness, and probing depths characteristic of endodontic failure) to form the final outcomes assessment of *complete healing*, *reductive healing,* or *failure*.

Statistical Analysis

Statistical analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC). Interrater agreements before examiners reaching consensus and intrarater agreements were calculated by using the Cohen kappa statistic. Kappa values 0.00-0.20 were considered “no agreement,” 0.21-0.39 “minimal,” 0.40-0.59 “weak,” 0.60-0.79 “moderate,” 0.80-0.90 “strong,” and > 0.90 “almost perfect” (15). Significance was set to $P < .05$.

Results

Twenty-four teeth from 23 patients (15 females and 9 male2, all ASA I or II) met the inclusion criteria with recall occurring between 12-28 months after treatment. The mean patient age was 42 years (range, 23-67 years). The characteristics of the included TEMS cases is shown in

Table 1. With regard to case selection in this cohort, TEMS was generally used over freehand osteotomy in cases with increased anatomic complexity. Of the 24 teeth, 2 were resurgery treatments of both the mesial facial (MF) and distal facial (DF) roots of a maxillary first and a maxillary second molar (Fig. 1*A-C*). Nine teeth received bone grafting with autogenous crushed bone, RegenerOss Allograft Putty (BIOMET 3i, LLC, Palm Beach Gardens, FL), Bio-Oss Collagen (Geistlich, Wolhusen, Switzerland), PAD Demineralized and Allowash XG Sterilized Bio-Implants (Stryker CMF, Kalamazoo, MI), Novabone Dental Putty (NovaBone Products, Jacksonville, FL), CollaPlug (Zimmer Dental, Warsaw, IN) or a combination of these materials. Of the 9 grafted cases, 1 received a Bio-Gide (Geistlich) membrane. Combined clinical and radiographic data led to 20 designations of *complete healing*, 2 designations of *reductive healin*g and 2 *failures* yielding a 91.7% success rate. One failure occurred in a 44-year-old ASA II female who did not receive a bone graft and had recall percussion and palpation tenderness despite a radiographic presentation of complete osseous healing (Fig. 3*M-O*). The second failure occurred in a 25-year-old, ASA II man who received PAD Demineralized and Allowash XG Sterilized Bio-Implants, Novabone Dental Putty, and autogenous bone on the distal root; had recall percussion and palpation tenderness; and was also classified as a radiographic failure (Fig. 4*J-L*). When considered independent of clinical findings, radiographic criteria for *complete healing* were met by 20 cases, *reductive healing* by 3 cases, and “radiographic” *failure* in 1 case.

Raters reached consensus for radiographic assessment in all cases. Before consensus, interrater Cohen kappa coefficients were 0.25 (95% confidence interval [CI], 0.02 – 0.48, P = .05) for session 1, indicating “minimal” agreement, and 0.77 (95% CI, 0.43 – 1.00; P < .05) for session 2 indicating “moderate” agreement. Session 2 had a significant interrater agreement. The intrarater Cohen kappa coefficients were 0.43 (95% CI, 0.19 – 0.69, P < .05) for both raters indicating “weak” agreement; 0.77 (95% CI, 0.50 – 1.00; P < .05) for rater 1, indicating “moderate” agreement, and 0.21 (95% CI, -0.05 to 0.46; P = .50) for rater 2 indicating “minimal” agreement. Rater 1 and the combined ratings had a significant intrarater agreement.

Discussion

This retrospective outcomes assessment is a preliminary indication that TEMS-guided trephine bur root-end resection leads to successful outcomes at rates similar to those established for freehand EMS carbide and diamond bur resections (8-10). Further, all but 4 cases showed complete healing on PA radiography 12-28 months after surgery, which is in keeping with prior evidence that osteotomies restricted to 5 mm (all TEMS osteotomies were 5 mm or less) exhibit enhanced healing (5). In this cohort, with 1 exception, TEMS was performed with a separate trephine osteotomy for each root. Fig. 1*A-C* shows a dual resurgery in which the MF root of tooth #2 and the DF root of tooth #3 were resected within one 5-mm trephine osteotomy pathway with a single surgical guide. A similar scenario occurs in cases of fused facial and palatal roots of maxillary molars in which a single facial approach TEMS pathway can resect both roots. We further speculate that healing after TEMS may partially be due to time savings during osteotomy and resection with overall reduced surgical time. However, TEMS intraoperative efficiency gains have only been documented in surgical simulations and clinical investigation is required to substantiate this speculation (4).

Of note, 70.8% of cases in this cohort presented with anatomic complexities that may have precluded treatment without a surgical guide: palatal approaches to the palatal roots of maxillary first and second molars (Fig. 1*D-O;* Fig. 2*A-F*), facial roots of maxillary second molars (Fig. 1*A-C, G-L*), maxillary first and second molar resurgery (Fig. 1*A-C*), distal roots of mandibular first molars (Fig. 3*G-L;* Fig. 4*A-O*), mesial and distal roots of mandibular second molars (Fig. 3*A-F*). Such complexities did not result in decreased success for teeth that may have otherwise required extraction. Indeed, many of these difficult surgeries were performed by novice residents, highlighting the enabling characteristics of TEMS.

Looking more closely at the 2 failures, the mandibular molar received bone grafting from autogenous and exogenous sources for both the mesial and distal osteotomy. At follow-up, the distal site showed radiographic healing. However, pain to percussion and palpation and expanded lesion size for the mesial root resulted in a failure designation. It is possible that bone grafting may have played a role in this failure (Fig. 4*J-L*). Sixteen months after surgery, the second failure, an otherwise asymptomatic tooth #28, was painful to percussion and palpation despite radiographic evidence of complete osseous healing (Fig. 3*M-O*). Cognitive dissonance in PA radiograph-based outcomes assessment could arise in part because of the inability to appreciate what is occurring in 3 dimensions (16, 17). Anatomic structures such as the zygoma, alveolus, and facial roots often obscure palatal root periradicular appearance. For the 6 palatal root cases included in this study, evaluators saw no radiographic signs of failure and no clinical signs of failure leading to an outcome designation of complete healing (Figs. 1*F*, 1*I*, 1*L*, 1*O*, 2*C*, 2*F*). PA-based outcome assessments have up to a 35% false-negative rate and a 16.5% false-positive rate for detection of osseous lesions as compared with CBCT-based assessments (14). Thus, the lack of recall CBCT images for this cohort represents an important limitation of these data. Furthermore, radiographic outcome assessments are complicated when bone grafting materials are placed into the osseous crypt, potentially masking radiographic signs of apical periodontitis at recall. However, in the absence of a radiolucency, signs, or symptoms at recall, an outcomes designation of *failure* would be difficult to justify for bone-grafted cases.

Outcomes assessment after endodontic surgery is inherently complex for the following reasons: potential bias of evaluators, inability to objectively quantify subjective experience, inconsistency in radiographic and CBCT interpretation, and inherent conceptual ambiguity (Is it biologically expected for *healed* cases to possibly have altered or aberrant sensation after a surgical intervention? What is tenderness? What is sensitivity? What is “just feels different?”). The surrogate measures of healing currently used provide a *reasonable* understanding of what is *likely* occurring in *most* cases. Histologic correlations are subject to potential incongruity as is seen in studies that attempt to relate symptoms to histologic findings and in the cyst versus granuloma literature (18-23). Therefore, it is important to recognize that limitations of outcomes assessments of *biologic* and *subjective* reality and that strict binary categories of “success” and “failure” although helpful might best be supplanted by understanding of healing upon a continuum, taking into account all of the factors that determine if a treated tooth contributes to the patient’s present well-being and if it is likely to continue to do so into the future.

The 3-category outcomes assessment model we used allowed balanced consideration of clinical and radiographic findings. *Complete healing* and *reductive healing* cases were deemed *successful*, by definition lacking signs or symptoms with radiographic complete osseous fill or a reduction in lesion size. This approach might potentially privilege normal signs and symptoms over radiographic appearance in cases in which lesion resolution is incomplete. Conversely, a case with apparent complete radiographic healing and reestablishment of a periodontal ligament space could also be deemed a failure if signs or symptoms were present (Fig. 3*M*-*O*). PA lesions that have reduced in size without complete resolution can be best understood, for outcomes purposes, through histologic evaluation, but specimens cannot be harvested at the recall examination. Interestingly, TEMS provides a viable way of assessing apical tissues of failed root canal treatment or retreatment with core samples containing bone, root end and PA lesion with associated biofilms (1). TEMS tissue cores might prove useful in further refining outcomes assessment models for classification of teeth with lesions that have reduced in sized without complete osseous fill.

The small sample size precluded investigation of prognostic factors, and TEMS was not compared with another intervention. Therefore, statistical analysis was limited to rater agreement. In all cases, raters achieved consensus. However, the results indicated preconsensus differences between raters and inconsistency of raters agreeing with themselves 7 days later, highlighting inherent limitations of subjective assessment of 2-dimensional PA radiographs. This study was not prospectively designed or performed with a view to a larger-scale study; yet, it might best be considered as fulfilling the role of a pilot study, prompting large-scale controlled clinical trials with long-term follow-up.

Conclusion

This limited retrospective outcomes assessment is an early indication that TEMS-guided trephine bur root-end resection leads to successful outcomes at rates similar to those established for freehand carbide and diamond bur resections. Controlled clinical trials with long-term follow-up are warranted.

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Table 1 Characteristics of Included Targeted Endodontic Microsurgery Cases with Follow-Up Time in Months

Tooth number	Roots treated	Treatment type	Graft material	Root-end filling material	Age/sex	Follow-up time	Outcome designation	Figure
2	MF	Resurgery	None	ES RRM	67/male	19	Complete healing	1*A–C*
3	DF	Resurgery	None	ES RRM	67/male	19	Complete healing	1*A–C*
2	Palatal	Initial	None	ES RRM	67/female	18	Complete healing	1*D–F*
2	MF, DF, palatal	Initial	Bio-Oss Collagen	ES RRM	46/female	12	Complete healing	1*G–I*
2	MF, DF, palatal	Initial	Bio-Oss Collagen	ES RRM	63/male	16	Complete healing	1*J–L*
3	MF, DF, palatal	Initial	Bio-Oss Collagen (palatal root only)	ES RRM	44/female	14	Complete healing	1*M–O*
14	MF, DF, palatal	Initial	Bio-Oss Collagen (palatal root only)	ES RRM	42/female	20	Complete healing	2*A–C*
15	Palatal	Initial	CollaPlug	MTA	23/male	16	Complete healing	2*D–F*
18	M, D	Initial	None	ES RRM	25/male	15	Complete healing	3*A–C*
18	M, D	Initial	autogenous bone, RegenerOss Allograft Putty	ES RRM	36/male	17	Complete healing	3*D–F*
30	D	Initial	None	ES RRM	35/female	17	Complete healing	3*G–I*
30	D	Initial	Bio-Oss Collagen, Bio-Gide	ES RRM	38/female	20	Complete healing	3*J–L*
28	Single root	Initial	None	ES RRM	44/female	16	Failure	3*M–O*
30	M, D	Initial	RegenerOss Allograft Putty	ES RRM	52/female	13	Complete healing	4*A–C*
30	M, D	Initial	None	ES RRM	41/female	13	Reductive healing	4*D–F*
30	M, D	Initial	None	ES RRM	42/female	16	Complete healing	4*G–I*
30	M, D	Initial	PAD Demineralized and Allowash XG, NovaBone Dental Putty, autogenous bone (D root only)	ES RRM	25/male	14	Failure	4*J–L*
30	M, D	Initial	None	ES RRM	28/female	17	Reductive healing	4*M–O*
7	Single root	Initial	None	ES RRM	48/female	28	Complete healing	NA
20	Single root	Initial	None	ES RRM	39/male	16	Complete healing	NA
10	Single root	Initial	None	ES RRM	36/female	13	Complete healing	NA
20	Single root	Initial	None	ES RRM	49/female	15	Complete healing	NA
20	Single root	Initial	None	MTA	25/male	14	Complete healing	NA
19	M	Initial	None	ES RRM	36/female	21	Complete Healing	NA

D, distal; DF, distal facial; ES RRM (EndoSequence BC RRM); M, mesial; MF, mesial facial; MTA (ProRoot MTA): NA, not available.

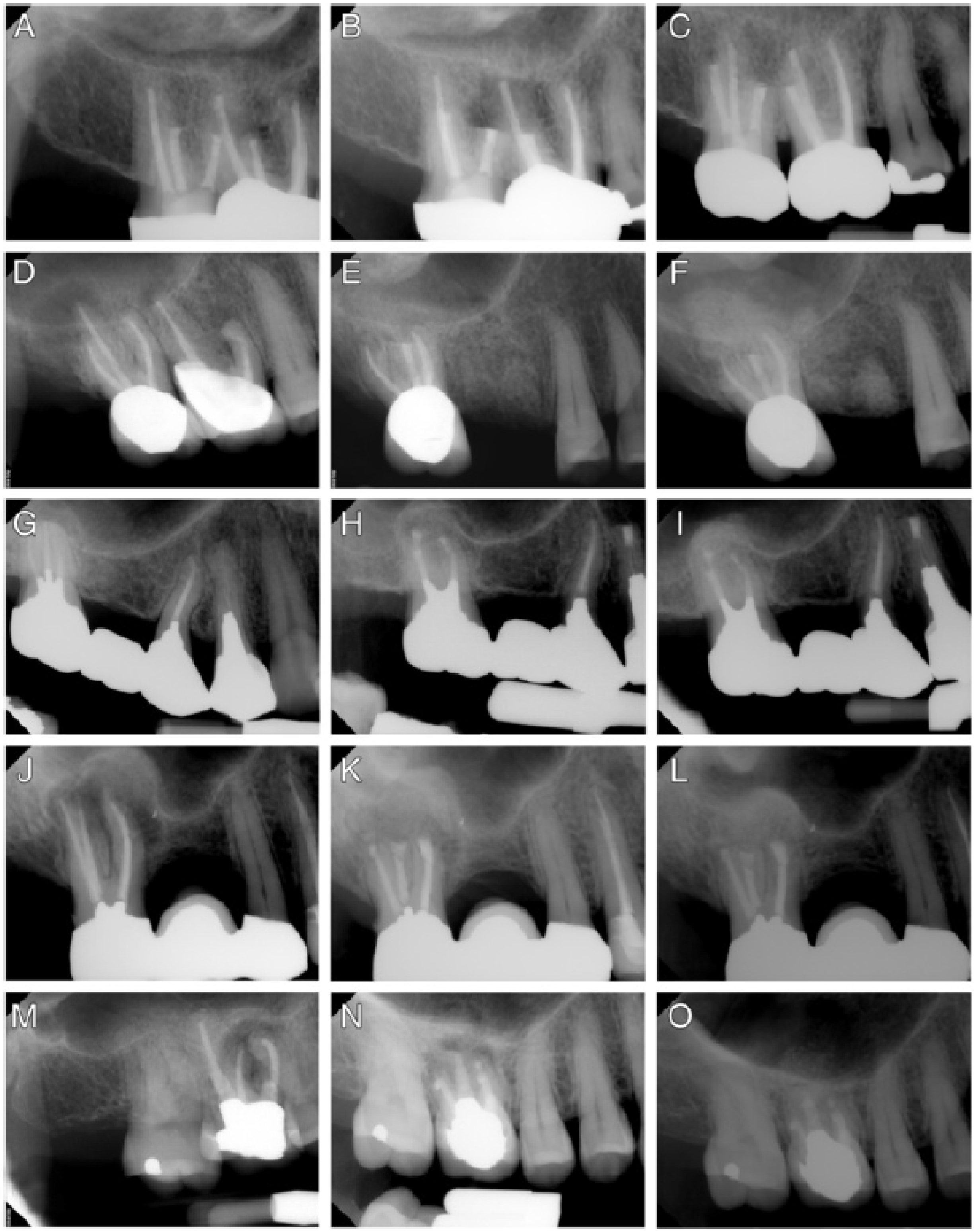

Figure 1 Representative PA radiographs of right maxillary posterior TEMS cases: (*A, D, G, J,* and *M*) presurgical, (*B, E, H, K,* and *N*) immediate postsurgical, and (*C, F, I, L,* and *O*) follow-up. (*A*–*C*) Tooth #2 MF and tooth #3 DF roots. (*D*–*F*) Tooth #2 palatal root. (*G*–*I*) Tooth #2 MF, DF, and

palatal roots with bone graft. (*J*–*L*) Tooth #2 MF, DF, and palatal roots with bone graft. (*M*–*O*) Tooth #3 MF, DF, and palatal roots with bone graft.

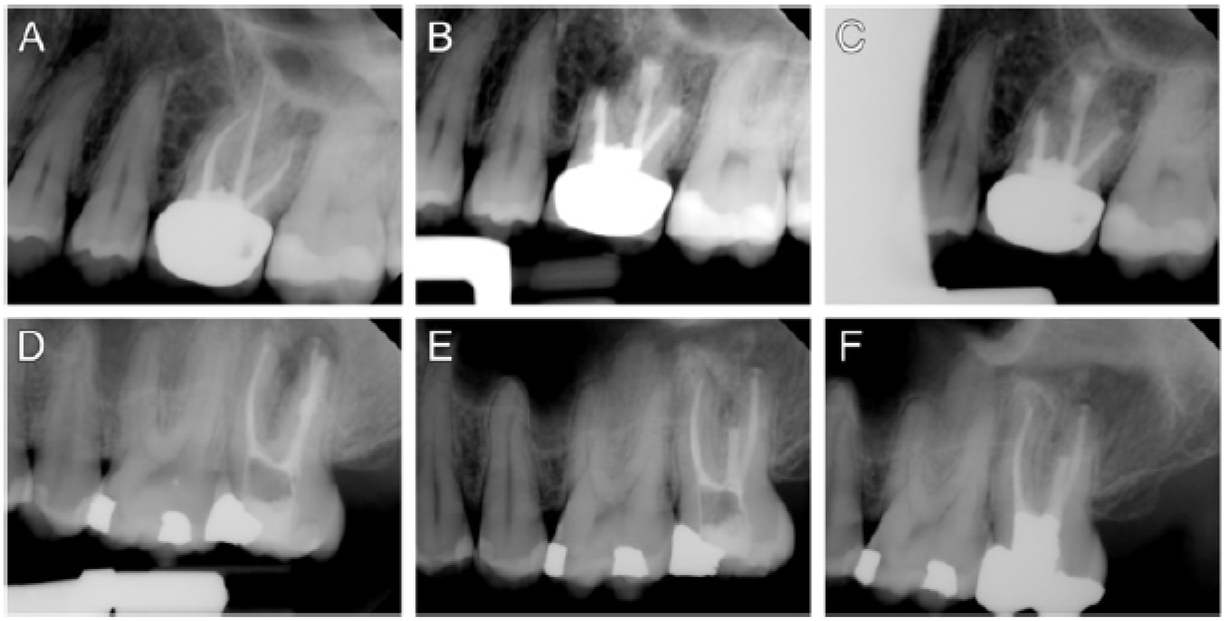

Figure 2 Representative PA radiographs of left maxillary posterior TEMS cases: (*A* and *D*) presurgical, (*B* and *E*) immediate postsurgical, and (*C* and *F*) follow-up. (*A*–*C*) Tooth #14 MF, DF, and palatal roots with bone graft. (*D*–*F*) Tooth #15 palatal root with bone graft.

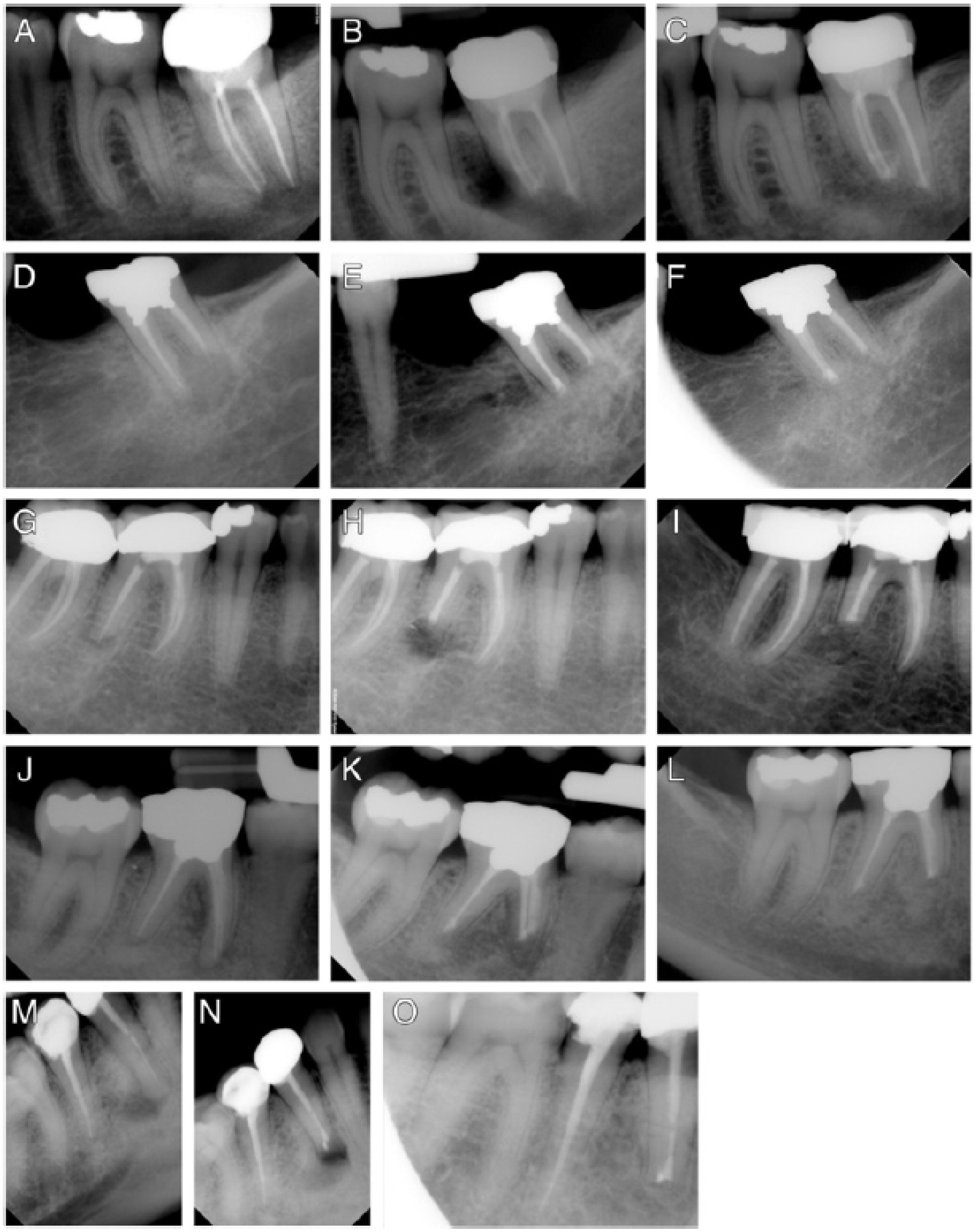

Figure 3 Representative PA radiographs of left and right mandibular posterior TEMS cases: (*A, D, G, J,* and *M*) presurgical, (*B, E, H, K,* and *N*) immediate postsurgical, and (*C, F, I, L,* and *O*) follow-up. (*A*–*C*) Tooth #18 mesial and distal roots. (*D*–*F*) Tooth #18 mesial and distal roots with bone graft. (*G*–*I*) Tooth #30 distal root. (*J*–*L*) Tooth #30 distal root received TEMS with bone

graft; #30 mesial root received freehand osteotomy and resection. (*M–O*) Tooth #28, failed case demonstrating recall percussion and palpation tenderness.

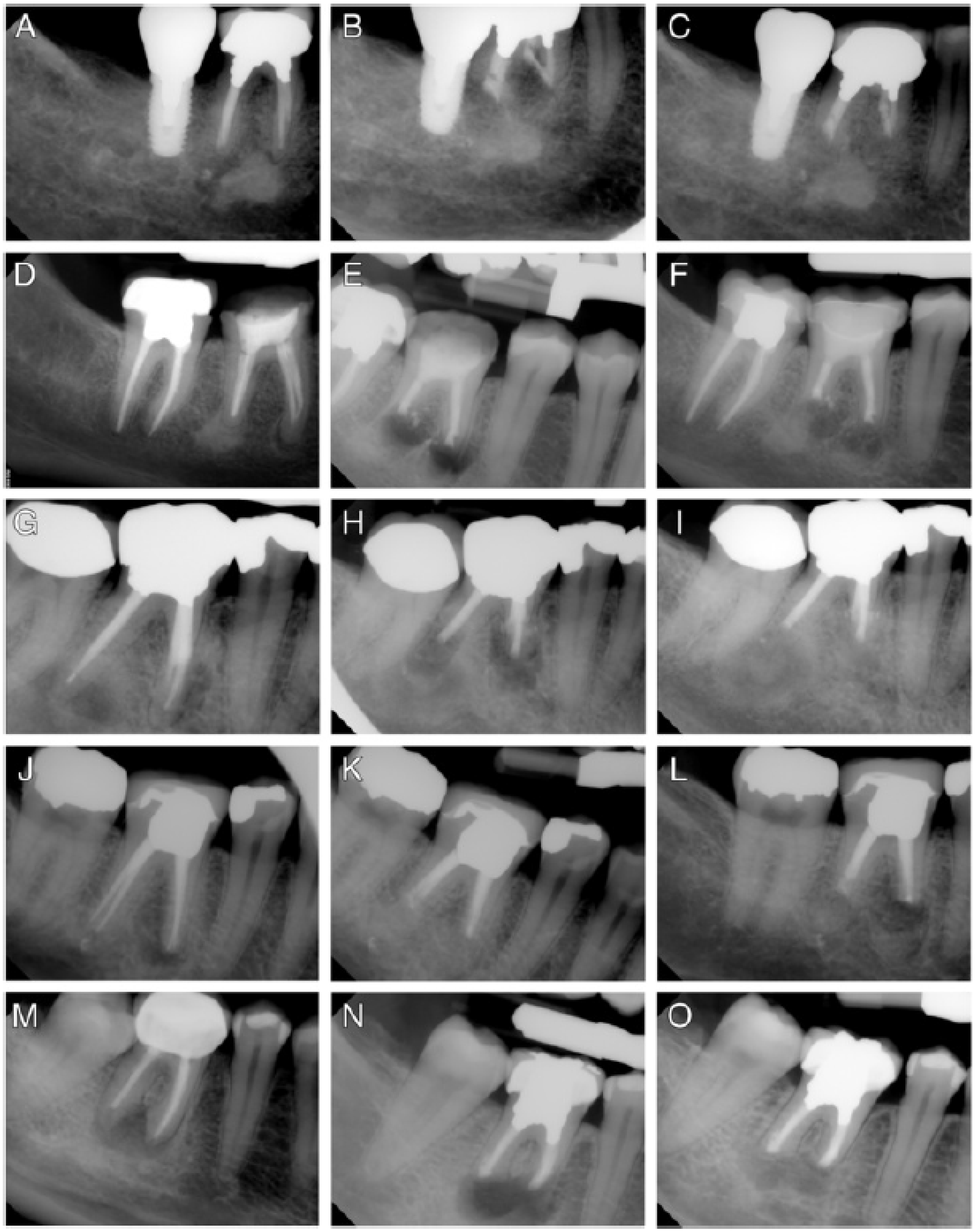

Figure 4 Representative PA radiographs of right mandibular posterior TEMS cases: (*A, D, G, J,* and *M*) presurgical, (*B, E, H, K,* and *N*) immediate postsurgical, and (*C, F, I, L,* and *O*) follow-up. (*A*–*C*) Tooth #30 mesial and distal roots with bone graft. (*D*–*F*) Tooth #30 mesial and distal roots. (*G*–*I*) Tooth #30 mesial and distal roots. (*J*–*L*) Tooth #30 mesial and distal roots with bone graft, failed case demonstrating recall percussion and palpation tenderness and classified as a radiographic failure. (*M*–*O*) Tooth #30 mesial and distal roots.