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Prognostic Predictors of Endodontic Microsurgery: Radiographic Assessment

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ABSTRACT

Objective: This study aimed to compare the healing outcomes of endodontic microsurgery (EMS) using 2-dimensional (2D) and 3-dimensional (3D) radiographic evaluation in a Chinese population. The prognostic factors of EMS were identified according to the 2D and 3D healing classifications.

Materials and methods: The teeth (n = 82) were studied using 2D and 3D radiographic examinations. The 2D and 3D healing criteria were used to evaluate the healing outcome. Prognostic factors were investigated based on healing outcomes. Data were analysed using SPSS, and $P < .05$ was considered significant.

Results: There were significant differences between 2D and 3D healing outcomes ($P = .004$). For the 3D images, age older than 45 years was found to be a significant negative predictor ($P = .005$).

Conclusions: Cone-beam computed tomographic images provided more precise evaluation of periapical lesions and healing outcomes of EMS than conventional periapical radiographs. Age (>45 years) of the patients exhibited a significant influence on the healing outcome of EMS as determined using 3D images.

Introduction

Endodontic microsurgery (EMS) is a surgical endodontic retreatment approach characterised by modern microsurgical techniques that integrate the use of an operating microscope or endoscope, root-end cavity preparation with ultrasonic tips, and more biocompatible root-end filling materials such as immediate restorative material, super ethoxybenzoic acid, or mineral trioxide aggregate.[1] The overall pooled success rate of EMS is more than 90%.[2,3] Its success is usually assessed through radiographic and clinical examinations during follow-up.[4] In endodontics, conventional periapical radiographs (CPRs) are commonly used to visualise osseous healing outcomes after EMS.[5]

CPR is the most common radiographic examination for routine clinical use. Rud's and Molven's criteria have been developed as efficacy diagnostic criteria for 2-dimensional (2D) images.[6,7] CPR is used to detect lesions when there is perforation of the cortical plate or erosion of the inner or outer surface of the cortex.[8] Diagnostic reliability is compromised by limitations of 2D imaging. Greater than 30% of mineral content loss of bone is a radiographic change that can only be captured during CPR screening.[9] Moreover, geometric distortion and overlying anatomic structures may make it difficult to demonstrate true bone changes.[10]

Cone-beam computed tomography (CBCT) visualisation of the true extent of periapical lesions and their proximity to important vital structures and anatomical landmarks is superior to that of CPR.[11] Recently, Keerthana et al compared the accuracy of CPR and CBCT in detecting complex endodontic pathoses. A prospective study reported that CBCT had better diagnostic accuracy for periapical lesions, root perforations, apicomarginal bone defects, and through-to-through bone defects.[12] In another study, 125 cases of EMS were assessed using preoperative CBCT images. The buccal cortical bone status was accurately predicted.[13] Recently, CBCT has been

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accepted as a reliable tool for the assessment of EMS outcomes.[8,14-16] A retrospective study concluded that postoperative CBCT imaging was more sensitive and specific than CPR in assessing periapical radiolucency and was useful in outcome assessment.[8] Schloss et al also reported that CBCT images presented a more precise healing evaluation for EMS. In this study, modified PENN 3-dimensional (3D) criteria were introduced, which proposed a detailed evaluation grading.[14]

Although CBCT has shown superior detection of periapical bone lesions,[12,17,18] few studies have used CBCT healing criteria[14] to evaluate the healing outcomes and prognostic factors of EMS. The purpose of this study was to compare the healing outcomes of EMS using these 2 radiographic examinations in a Chinese population. Evaluating prognostic factors accurately based on reliable healing outcomes assessed using 3D images might be valuable. Therefore, we investigated the potential prognostic factors based on postoperative CPR healing criteria[6,7] and CBCT healing criteria[14] in a Chinese population.

Materials and methods

Sample selection

The study was approved by the Ethics Committee of the School and Hospital of Stomatology (2017B03), Wuhan University. Patients who underwent EMS performed by 2 experienced endodontic specialists (L.M., R.Z.) in the Hospital of Stomatology from 2012 to 2016 were selected from the medical database of Wuhan University. Patients whose follow-up period was more than 1 year were called or emailed to undergo examination for EMS. The participants were fully informed of all potential risks and provided signed informed consent. Data were collected according to the inclusion/exclusion criteria. During the follow-up period, clinical symptoms and radiographic assessments were collected.

1. Inclusion and exclusion criteria
   - 1.1 The inclusion criteria were as follows:
     - (1) Radiologically and clinically intact restorations at follow-up
     - (2) History of primary EMS
     - (3) Available preoperative and postoperative CPR and CBCT
     - (4) Minimum 1-year follow-up period
   - 1.2 The exclusion criteria were as follows:
     - (1) Patients with a history of systemic disease
     - (2) Teeth with root perforation or apical cracks
     - (3) History of other endodontic surgery
     - (4) Lack of preoperative and/or postoperative CPR and CBCT examination
     - (5) Less than 1-year follow-up
     - (6) Incomplete restoration, either radiologically or clinically, at follow-up
2. *EMS Procedures*

   EMS procedures included incision, full mucoperiosteal flap elevation, and root resection using a surgical operating microscope. Root end resection was performed in all cases. All root ends were prepared using ultrasonic tips and filled with mineral trioxide aggregate (MTA, Dentsply Tulsa Dental) under an operating microscope. All included teeth were operated on under EMS guidelines.[19] All clinical procedures were performed by 2 experienced endodontic specialists, as mentioned previously.
3. *Clinical and Radiographic Evaluation*

   Clinical examination recorded the presence of symptoms (pain, sensitivity to percussion, and/or palpation) and signs (fistula, swelling). Radiographic assessment was performed using not only the CPR healing criteria[6,7] but also the CBCT healing criteria.[14] Radiographic assessment was performed using both Rud's and Molven's criteria and modified PENN 3D criteria.[6,,7,14]
   - 3.1 Radiographic Evaluation and Criteria for CPR

     CPR was performed using an X-ray unit operating at 60 kV and 7 mA (Planmeca). The outcomes of EMS were classified into 4 types: complete healing, incomplete healing, uncertain healing, and unsatisfactory healing according to Rud's and Molven's criteria.[6,7] The assessment was performed independently by 2 departmental endodontists (C.Y., Z.W.). Any disagreement between the 2 examiners was resolved through discussion. Agreement between the faculty members regarding healing outcomes was compared using Cohen's kappa statistics. Finally, the failed cases were those with radiographic evidence of uncertain or unsatisfactory healing. Complete healing and incomplete healing without clinical signs or symptoms were dichotomised as successful. Cases in which teeth were extracted because of persistent clinical symptoms were also regarded as failed cases.
   - 3.2 Radiographic Evaluation and Criteria for CBCT

     The CBCT images were obtained using a CBCT machine operating at 110 kV and 3.41 mA (Newtom VGi) with a voxel size of 0.2 mm. The maximum diameter and volume of the apical lesions were measured on preoperative CBCT images using Mimics software (Materialize). The periapical bone defect diameter was measured in 3 axial orientations (mesiodistal, apicocoronal, and buccolingual), and the maximum diameter was recorded. The volumes of the radiolucent lesions were counted as more than twice the width of the periodontal ligament. The data were measured by C.Y. and Z.W. The modified PENN 3D criteria were used to evaluate EMS healing on postoperative CBCT images.[14] Complete healing and limited healing with no clinical signs or symptoms were considered successful. Meanwhile, uncertain healing and unsatisfactory healing were labeled as failures. Cases in which teeth were extracted because of persistent clinical symptoms were regarded as failures.
4. *Investigated Factors*

   Factors possibly influencing the surgical outcome were recorded as patient-related factors (sex and age) and tooth-related factors (tooth type, arch type, maximum lesion size, preoperative bone palate defect, preoperative lesion volume, probing depth, and restoration type). These factors were evaluated during clinical and radiographic examinations.

Statistical analysis

The kappa test was used to calculate observer reliability. To confirm significant prognostic factors, chi-square tests or Fisher's exact tests were applied for univariate factors. Finally, all univariate factors with a significance level of 0.2 were assessed using the logistic regression model. The comparison of EMS healing outcomes between CPR and CBCT was performed using McNemar's test.

Results

A total of 76 patients receiving primary EMS at least 1 year previously returned to undergo postoperative examination. According to the inclusion and exclusion criteria, 55 patients (82 teeth) were assessed in this study. The mean follow-up duration was 28 months. The patients' ages ranged from 12 to 52 years. Of the 55 patients, 34 were male and 21 were female. The weighted kappa value between the 2 examiners for healing outcomes was 0.803. The Cohen's kappa value between the 2 examiners for lesion size and lesion volume ranged from 0.829 to 0.943. The analysis showed that the success rate of EMS was 95.1% (78/82) and 84.1% (69/82) as evaluated using CPR and CBCT images, respectively. The outcome assessment between CPR and CBCT images was significantly different ($P = .004$). There were no prognostic factors that had a statistically significant influence on the outcome of EMS identified using CPR evaluation. However, preoperative maximum lesion size >12 mm was a potential factor in the univariate analysis based on CBCT evaluation ($P = .034$) (Table 1). Patients aged ≤45 years were found to have better healing outcomes in the univariate analysis ($P = .002$) (Table 1) and logistic regression model ($P = .005$) (Table 2).

Table 1 – Distribution of investigated factors and analysis in the evaluated cases.

Factors	Cases	Success rate (%)		*P* value	
		CPR	CBCT	CPR	CBCT
Sex				.308	.783
Female	47	97.9	85.1		
Male	35	91.4	82.6		
Age				.226	.002*
≤45 y	77	96.1	88.3		
>45 y	5	80.0	20.0		
Preoperative probing depth				.562	.281
≤3 mm	67	95.5	82.1		
4-6 mm	15	93.3	93.3		
Restoration type at follow-up				.246	.169
Direct restoration	49	91.8	79.6		
Indirect restoration	33	100.0	90.9		
Tooth type				1.000	1.000
Anterior	77	94.8	83.1		
Posterior	5	100.0	100.0		
Arch type				.444	.829
Maxilla	71	95.8	83.1		
Mandible	11	90.9	90.9		
Preoperative bone palate defect		0.569	0.279		
Yes	63	93.7	81.0		
No	19	100.0	94.7		
Maximum lesion size				1.000	.034*
≤12 mm	41	95.1	92.7		
>12 mm	41	95.1	75.6		
Preoperative volume (V (mm^3))				1.000	.109
≤500 mm^3	48	95.8	89.6		
>500 mm^3	34	94.1	76.6		
Total	82	95.1	84.1		.004#

Direct restoration: Teeth were restored by resin composite or glass ionomer cement.

Indirect restoration: Teeth were restored by full crown or onlay.

* $P < .05$ comparison of microsurgery healing outcome evaluated by 3-dimensional criteria between different factors.

\# $P < .05$ comparison of microsurgery healing outcome between CPR and CBCT.CBCT, cone-beam computed tomography; CPR, conventional periapical radiograph,

Discussion

Diagnostic sensitivity and specificity are clinically important in evaluating therapeutic methods and clinical conditions.[20] CPR is still the most used method for the diagnosis and assessment of healing outcomes. However, its diagnostic reliability is limited owing to image distortion and compression of 3D structures.[12] Persistent periapical lesions after EMS cannot be observed when anatomic noise or geometric distortion exist.[21] Ernest et al suggested that the inability of CPR to reveal true bone changes could potentially be overcome with the use of 3D images.[5]

CBCT shows more anatomic details by using 3D scanning images and is regarded as a powerful tool in diagnosis and follow-up.[14,15,22-25] Patal et al showed that CBCT examination was 100% successful in detecting the presence and absence of periapical lesions, whilst the sensitivity of CPR was 24.8%.[21] Endodontists believe that CBCT enhances the diagnosis of odontogenic pathologies, anatomical structures, treatment of iatrogenic errors, and diagnosis of nonodontogenic pathoses by 96.4%, 96.3%, 92.2%, and 88%, respectively.[26] Meanwhile, CBCT provided similar outcomes compared to the histologic results of animal studies.[27,28] In our study, there were significant differences between the CPR and CBCT outcomes. Of the 82 teeth in which there was a diagnostic disagreement, CBCT identified success in 9 teeth (11%) in which CPR did not. CBCT should be considered for better postoperative evaluation of EMS, especially with the advent of novel low-dose CBCT protocols in the future.

We assessed potential prognostic predictors according to healing outcomes revealed using CPR and CBCT. One patient-related variable (age) was evaluated as a significant prognostic factor according to the CBCT criteria,[14] whereas there were no significant factors found in the CPR[6,7] evaluation. Age was not significantly associated with the CPR criteria,[6,7] which is consistent with previous studies.[29,30] Barone et al reported that patients aged 45 years or older had better EMS outcomes, which is contradictory to our present study. In their study, the outcome was assessed using a 2D imaging modality, and they did not provide much explanation for this result.[31] The disparity may be due to the different evaluation methods and inclusion and exclusion criteria. Previous studies have also shown that patient-related factors (ie, sex and

Table 2 – Logistic regression model of investigated factors with significance in univariate analysis.

Independent variables	P value	Odds ratio	95% CI	
			Lower	Upper
Restoration type at follow-up	.162	3.313	0.610	17.982
Maximum lesion size (≤12 mm)	.127	0.206	0.027	1.569
Preoperative volume (≤500 mm^3)	.620	1.598	0.250	10.203
Age (≤45 y)	.005*	0.031	0.003	0.351

Odds ratio shows the failure rate.
Restoration type is as follows:
Direct restoration: Teeth were restored by resin composite or glass ionomer cement .
Indirect restoration: Teeth were restored by full crown or onlay.

* $P < .05$ comparison of microsurgery healing outcome evaluated by 3-dimensional criteria between different factors.

age) did not seem to influence surgical outcomes.[32,33] In the present study, age older than 45 years was found to be a negative predictor based on the CBCT criteria. It is possible that younger patients had better healing capacity.[34] Some authors have shown that female patients experience a higher success rate than male patients.[26,35] However, our study showed that there was no significant difference between sexes in both CPR[6,7] and CBCT[14] evaluation, which is consistent with previous studies.[35-39]

Regarding tooth-related factors, some studies have shown that maxillary teeth had a higher success rate than mandibular teeth.[30,32,40] This may be related to access to the surgical approach, complexity of the root canal anatomy, presence of isthmus, and axis of root canal preparation, amongst other factors.[40] Our study demonstrated that arch type (maxilla 77, mandible 11) was not a significant prognostic factor, which is consistent with the results of previous studies.[39,41] Differences between anteriors and molars were significant, whereas differences between anteriors and premolars were not.[42] This may be due to the comparably difficult surgical access required for premolars and molars, together with the reduced visibility. Clinicians are advised to prudently select posteriors for EMS and consider treatment alternatives. In addition, several previous studies also showed greater success for anterior teeth,[43,44] which may be explained by easier surgical access and less complex root canal anatomy.[32] Von Arx et al[45] showed a higher success rate for maxillary molars (95.2%) than for maxillary premolars (66.7%). Nevertheless, other studies have reported different results regarding this factor.[1,40,46] Regarding tooth type, there was no significant difference between anterior and posterior teeth in our study, which might be related to the small sample size of posteriors.

Previous studies showed that lesion size was also a significant factor as evaluated using the CPR criteria,[6,7] and the size for statistical analysis varied. It was reported that the failure rate for EMS for preoperative lesions >5 mm, >6 mm, or >10 mm increased based on CPR evaluation.[32,33,35,39] Von Arx et al reported that healed cases had a smaller apical bone defect (7.04 mm) than that of non-healed cases (8.60 mm).[47] Few studies have analysed the diameter of apical lesions using CBCT. In our study, the failure rate was significantly higher with a maximum lesion size of >12 mm. A lesion size of 12 mm was selected for statistical analysis because it was median value of the total distribution (12.08 mm ± 5.31 mm) in our study. It is not easy to remove residual tissue of a larger lesion thoroughly during EMS, which may lead to persistent inflammation.[26] A similar study suggested that a large lesion size (>10 mm) is one of the major factors influencing the prognosis, as these lesions demonstrate a significantly lower rate of complete healing, with an increased rate of incomplete healing rather than failure.[23] In addition, a previous study evaluated based on CPR showed that preoperative lesion size <12 mm had a higher success rate, which is consistent with our results.[40]

It has been shown that the success rate of the mean size of the bony crypt (395 ± 41.66 mm^3) was significantly different from those in non-healed cases (554 ± 51.61 mm^3).[47] Kreisler et al reported that cases with smaller lesions had a higher probability of healing.[48] Kim et al reported that cases with lesion volumes greater than 50 mm^3 had significantly lower success rates.[4] The difference in volumes greater than 500 mm^3 was not identified in the present analysis. The inconsistency of lesion volume may be caused by different inclusion and exclusion criteria of cases or different stages of the measurement.[47,48]

The limitations of the present study include the relatively small sample size, which influences statistical power. In addition, there was a maldistribution of the anterior and posterior teeth, possibly because of difficult access to the surgical approach. More participants older than 45 years of age and more posterior teeth should be included in subsequent research to verify the results. Although CBCT has shown superiority over CPR in evaluating the healing outcome of EMS, it is not routinely used for assessment during the follow-up period because of its higher costs and higher levels of radiation exposure over those of CPR. A possible solution may be the advent of a novel low-dose CBCT protocol in the future.

Conclusions

The healing outcomes were significantly different between CPR and CBCT images. Postoperative CBCT imaging is more sensitive and specific than CPR for assessing healing outcomes following endodontic microsurgery. Age older than 45 years was related to a lower probability of successful healing as evaluated using CBCT criteria.

Conflict of interest

None disclosed.

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Author contributions

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REFERENCES

1. Pinto D, Marques A, Pereira JF, Palma PJ, Santos JM. Long-term prognosis of endodontic microsurgery-a systematic review and meta-analysis. Medicina (Kaunas) 2020;56(9):447. doi: 10.3390/medicina56090447.
2. Garcia C, Quijano S, Molano N, Antonio Pineda G, Niño-Barrera J, Marín-Zuluaga D-J. Predictors of clinical outcomes in endodontic microsurgery: a systematic review and meta-analysis. Giornale Italiano di Endodonzia 2017;31:2–13.
3. Setzer FC, Shah SB, Kohli MR, Karabucak B, Kim S. Outcome of endodontic surgery: a meta-analysis of the literature—part 1: comparison of traditional root-end surgery and endodontic microsurgery. J Endod 2010;36:1757–65. doi: 10.1016/j.joen.2010.08.007.
4. Tawil PZ, Trope M, Curran AE, et al. Periapical microsurgery: an in vivo evaluation of endodontic root-end filling materials. J Endod 2009;35(3):357–62. doi: 10.1016/j.joen.2008.12.001.
5. Lam EWN, Law AS, Nguyen RHN, et al. Interexaminer agreement in the radiologic identification of apical periodontitis/rarefying osteitis in the National Dental Practice-Based Research Network PREDICT Endodontic Study. J Endod 2021;47(10):1575–82. doi: 10.1016/j.joen.2021.07.008.
6. Molven O, Halse A, Grung B. Observer strategy and the radiographic classification of healing after endodontic surgery. Int J Oral Maxillofac Surg 1987;16:432–9. doi: 10.1016/s0901-5027(87)80080-2.
7. Rud J, Andreasen JO, Jensen JE. Radiographic criteria for the assessment of healing after endodontic surgery. Int J Oral Surg 1972;1:195–214. doi: 10.1016/s0300-9785(72)80013-9.
8. Curtis DM, VanderWeele RA, Ray JJ, Wealleans JA. Clinician-centered outcomes assessment of retreatment and endodontic microsurgery using cone-beam computed tomographic volumetric analysis. J Endod 2018;44(8):1251–6. doi: 10.1016/j.joen.2018.03.016.
9. Bender IB, Seltzer S. Roentgenographic and direct observation of experimental lesions in bone: I. 1961. J Endod 2003;29(11):702–6 discussion 701. doi: 10.1097/00004770-200311000-00005.
10. Bender IB. Factors influencing the radiographic appearance of bony lesions. J Endod 1997;23(1):5–14. doi: 10.1016/S0099-2399(97)80199-9.

[11]. Fayad MI. The impact of cone beam computed tomography in endodontics: a new era in diagnosis and treatment planning. American Association of Endondontists 2018.

12. G K, Singh N, Yadav R, et al. Comparative analysis of the accuracy of periapical radiography and cone-beam computed tomography for diagnosing complex endodontic pathoses using a gold standard reference – a prospective clinical study. Int Endod J 2021;54(9):1448–61. doi: 10.1111/iej.13535.
13. Mayo Jr CV, Replogle KJ, Marshall JG, et al. Accuracy of presurgical limited field of view cone-beam computed tomography in predicting intraoperative buccal cortical bone. J Endod 2020;46(2):169–77. doi: 10.1016/j.joen.2019.10.026.
14. Schloss T, Sonntag D, Kohli MR, Setzer FC. A comparison of 2- and 3-dimensional healing assessment after endodontic surgery using cone-beam computed tomographic volumes or periapical radiographs. J Endod 2017;43:1072–9. doi: 10.1016/j.joen.2017.02.007.
15. von Arx T, Janner SF, Hanni S, Bornstein MM. Agreement between 2D and 3D radiographic outcome assessment one year after periapical surgery. Int Endod J 2016;49:915–25. doi: 10.1111/iej.12548.
16. Song D, Zhang L, Zhou W, et al. Comparing cone-beam computed tomography with periapical radiography for assessing root canal obturation in vivo using microsurgical findings as validation. Dentomaxillofac Radiol 2017;46(5). doi: 10.1259/dmfr.20160463.
17. Leonardi Dutra K, Haas L, Porporatti AL, et al. Diagnostic accuracy of cone-beam computed tomography and conventional radiography on apical periodontitis: a systematic review and meta-analysis. J Endod 2016;42:356–64. doi: 10.1016/j.joen.2015.12.015.
18. Lo Giudice R, Nicita F, Puleio F, et al. Accuracy of periapical radiography and CBCT in endodontic evaluation. Int J Dent 2018;2018:2514243. doi: 10.1155/2018/2514243.
19. Floratos S, Kim S. Modern endodontic microsurgery concepts: a clinical update. Dent Clin North Am 2017;61(1):81–91. doi: 10.1016/j.cden.2016.08.007.
20. G K, Singh N, Yadav R, et al. Comparative analysis of accuracy of periapical radiography and cone beam computed tomography in diagnosing complex endodontic pathoses using a gold standard reference - a prospective clinical study. Int Endod J 2021;54(9):1448–61. doi: 10.1111/iej.13535.
21. Patel S, Dawood A, Mannocci F, Wilson R, Pitt Ford T. Detection of periapical bone defects in human jaws using cone beam computed tomography and intraoral radiography. Int Endod J 2009;42(6):507–15.
22. Kim D, Ku H, Nam T, Yoon TC, Lee CY, Kim E. Influence of size and volume of periapical lesions on the outcome of endodontic microsurgery: 3-dimensional analysis using cone-beam computed tomography. J Endod 2016;42:1196–201. doi: 10.1016/j.joen.2016.05.006.
23. Patel S, Durack C, Abella F, Shemesh H, Roig M, Lemberg K. Cone beam computed tomography in endodontics - a review. Int Endod J 2015;48::3–15. doi: 10.1111/iej.12270.
24. Jorge EG, Tanomaru-Filho M, Guerreiro-Tanomaru JM, Reis JM, Spin-Neto R, Goncalves M. Periapical repair following endodontic surgery: two- and three-dimensional imaging evaluation methods. Braz Dent J 2015;26:69–74. doi: 10.1590/0103-6440201300252.
25. von Arx T, Janner SF, Hanni S, Bornstein MM. Evaluation of new cone-beam computed tomographic criteria for radiographic healing evaluation after apical surgery: assessment of repeatability and reproducibility. J Endod 2016;42:236–42. doi: 10.1016/j.joen.2015.11.018.
26. Alzamzami ZT, Abulhamael AM, Talim DJ, Khawaji H, Barzanji S, Roges RA. Cone-beam computed tomographic usage: survey of American endodontists. J Contemp Dent Pract 2019;20(10):1132–7.
27. de Paula-Silva FW, Santamaria Jr M, Leonardo MR, Consolaro A, da Silva LA. Cone-beam computerized tomographic, radiographic, and histologic evaluation of periapical repair in dogs' post-endodontic treatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:796–805. doi: 10.1016/j.tripleo.2009.06.016.
28. Chen I, Karabucak B, Wang C, Wang HG, Koyama E, Kohli MR. Healing after root-end microsurgery by using mineral trioxide aggregate and a new calcium silicate-based bioceramic material as root-end filling materials in dogs. J Endod 2015;41:389–99. doi: 10.1016/j.joen.2014.11.005.
29. Wang ZH, Zhang MM, Wang J, Jiang L, Liang YH. Outcomes of endodontic microsurgery using a microscope and mineral

trioxide aggregate: a prospective cohort study. J Endod 2017;43 (5):694–8. doi: 10.1016/j.joen.2016.12.015.
30. Lui JN, Khin MM, Krishnaswamy G, Chen NN. Prognostic factors relating to the outcome of endodontic microsurgery. J Endod 2014;40(8):1071–6. doi: 10.1016/j.joen.2014.04.005.
31. Barone C, Dao TT, Basrani BB, Wang N, Friedman S. Treatment outcome in endodontics: the Toronto study−phases 3, 4, and 5: apical surgery. J Endod 2010;36:28–35. doi: 10.1016/j.joen.2009.09.001.
32. von Arx T, Penarrocha M, Jensen S. Prognostic factors in apical surgery with root-end filling: a meta-analysis. J Endod 2010;36:957–73. doi: 10.1016/j.joen.2010.02.026.
33. Zhou W, Zheng Q, Tan X, Song D, Zhang L, Huang D. Comparison of mineral trioxide aggregate and iRoot BP plus root repair material as root-end filling materials in endodontic microsurgery: a prospective randomized controlled study. J Endod 2017;43:1–6. doi: 10.1016/j.joen.2016.10.010.
34. Song M, Kim SG, Lee SJ, Kim B, Kim E. Prognostic factors of clinical outcomes in endodontic microsurgery: a prospective study. J Endod 2013;39:1491–7. doi: 10.1016/j.joen.2013.08.026.
35. Caliskan MK, Tekin U, Kaval ME, Solmaz MC. The outcome of apical microsurgery using MTA as the root-end filling material: 2- to 6-year follow-up study. Int Endod J 2016;49:245–54. doi: 10.1111/iej.12451.
36. Song M, Kim E. A prospective randomized controlled study of mineral trioxide aggregate and super ethoxy-benzoic acid as root-end filling materials in endodontic microsurgery. J Endod 2012;38:875–9. doi: 10.1016/j.joen.2012.04.008.
37. Taschieri S, Weinstein T, Tsesis I, Bortolin M, Del Fabbro M. Magnifying loupes versus surgical microscope in endodontic surgery: a four-year retrospective study. Aust Endod J 2013;39:78–80. doi: 10.1111/j.1747-4477.2011.00309.x.
38. Tawil PZ. Periapical microsurgery: can ultrasonic root-end preparations clinically create or propagate dentinal defects? J Endod 2016;42:1472–5. doi: 10.1016/j.joen.2016.07.016.
39. Von Arx T, Jensen SS, Hanni S, Friedman S. Five-year longitudinal assessment of the prognosis of apical microsurgery. J Endod 2012;38:570–9. doi: 10.1016/j.joen.2012.02.002.
40. Liao WC, Lee YL, Tsai YL, et al. Outcome assessment of apical surgery: a study of 234 teeth. J Formos Med Assoc 2019;118 (6):1055–61. doi: 10.1016/j.jfma.2018.10.019.
41. Li H, Zhai F, Zhang R, Hou B. Evaluation of microsurgery with SuperEBA as root-end filling material for treating post-treatment endodontic disease: a 2-year retrospective study. J Endod 2014;40:345–50. doi: 10.1016/j.joen.2013.11.001.
42. Yoo YJ, Kim DW, Perinpanayagam H, et al. Prognostic factors of long-term outcomes in endodontic microsurgery: a retrospective cohort study over five years. J Clin Med 2020;9 (7):2210. doi: 10.3390/jcm9072210.
43. Ogutlu F, Karaca I. Clinical and radiographic outcomes of apical surgery: a clinical study. J Maxillofac Oral Surg 2018;17:75–83. doi: 10.1007/s12663-017-1008-9.
44. Sutter E, Valdec S, Bichsel D, Wiedemeier D, Rucker M, Stadlinger B. Success rate 1 year after apical surgery: a retrospective analysis. Oral Maxillofac Surg 2020;24:45–9. doi: 10.1007/s10006-019-00815-9.
45. Von Arx T, Jensen SS, Janner SFM, Hänni S, Bornstein MM. A 10-year follow-up study of 119 teeth treated with apical surgery and root-end filling with mineral trioxide aggregate. J Endod 2019;45:394–401. doi: 10.1016/j.joen.2018.12.015.
46. Truschnegg A, Rugani P, Kirnbauer B, Kqiku L, Jakse N, Kirmeier R. Long-term follow-up for apical microsurgery of teeth with core and post restorations. J Endod 2020;46:178–83. doi: 10.1016/j.joen.2019.11.002.
47. Von Arx T, Hanni S, Jensen SS. Correlation of bone defect dimensions with healing outcome one year after apical surgery. J Endod 2007;33:1044–8. doi: 10.1016/j.joen.2007.06.010.
48. Kreisler M, Gockel R, Aubell-Falkenberg S, et al. Clinical outcome in periradicular surgery: effect of patient- and tooth-related factors−a multicenter study. Quintessence Int 2013;44 (1):53–60. doi: 10.3290/j.qi.a28742.