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치의과학 박사학위논문

**Prognostic Factors of Long-Term
Outcomes in Endodontic
Microsurgery: A Retrospective Cohort
Study over Five Years**

미세 치근단 수술의 예후에 미치는
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Prognostic Factors of Long-Term Outcomes in Endodontic Microsurgery: A Retrospective Cohort Study over Five Years

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2021 년 2 월

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Abstract

Prognostic Factors of Long-Term Outcomes in Endodontic Microsurgery: A Retrospective Cohort Study over Five Years

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The aim of this study was to analyze the long-term outcomes of endodontic microsurgeries in a cohort and identify their association with prognostic factors. A cohort of endodontic microsurgeries followed up periodically with complete clinical and radiographic records for at least 5 years were reviewed retrospectively. Their survival and healing status and profile characteristics were analyzed by Pearson chi-square test and logistic regression ($\alpha = 0.05$) to identify prognostic factors that

influenced outcomes. Of 652 cases in the cohort, 225 (34.5%) cases were included. The mean follow-up period was 90.4 months (range, 60–168 months). The long-term success rate was 80.5%, and the 5-year survival rate was 83.5%. Logistic regression showed higher success in anterior teeth compared to molars (OR = 5.405, (95% CI, 1.663–17.571; $P = 0.005$)) and in teeth with crown restorations (OR = 10.232, (95% CI, 3.374–31.024; $P < 0.001$)). Conversely, lower success was found in teeth with periodontal disease (OR = 0.170, (95% CI, 0.032–0.900; $P = 0.037$)) and maxillary sinus involvement (OR = 0.187, (95% CI, 0.035–0.994; $P = 0.049$)). Tooth position, crown restoration, periodontal disease, and maxillary sinus involvement were identified as main prognostic factors. Additionally, Kaplan–Meier survival analyses showed a 5-year survival rate of 83.5%. Cox proportional hazards regression analysis showed that tooth position, crown restoration at follow-up, pain on percussion, RPD abutments, and maxillary sinus involvement had significant effects on survival. Collective evidence supports that endodontic microsurgery has a highly favorable long-term outcome.

Keywords : cohort study; endodontic microsurgery; long-term outcome; prognostic factors; success rate; survival rate

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1. Introduction

Endodontic surgery could be a last resort treatment when persistent lesions from complicated root canal anatomy, cysts or extraradicular infections with failure of non-surgical root canal treatment [1, 2]. Root end resections and root end fillings

eradicate the source of infection to facilitate clinical and radiographic healing as outcome measurements.

Since the mid-1800s, surgical root canal treatment has been done, including root end resection [3]. The use of radiographs to help diagnose and use surgical burs to perform a rapid osteotomy and "ablation" of the root end was identified by Schamberg [4]. He presented a detailed, diagrammatic overview of the root-end resection technique used [4]. In the early 20th century, perhaps the single most significant advance in dental practice was the introduction of safe, reliable local anesthesia, which made surgical care more meticulous and comfortable [5]. Ross gave the first indication of the use of amalgam as root-end filling material when he defined the Castenfeldt's technique for the management of exposed dentin [4, 6]. In 1924, Blayney and Wach published an article on a research they performed to prove that new cement deposition and periodontal healing were possible on the surface of resected dentin [4, 6].

Traditional endodontic surgery has been performed with larger osteotomy size (approximately 8-10mm), steep root-end resection angle (45 degrees to the long axis of the root on average), root end preparation of the canal with burs, and root-end filling with silver amalgam [7]. It was difficult to examine the resected root surface with isthmus detection and treatment in traditional endodontic surgery. In addition, amalgam leads to corrosion and disintegration, and amalgam tattooing may lead to excess amalgam and the release of metal particles into the surrounding tissues. Also, the healing characteristics are questionable after root-end amalgam filling [8]. Thus, these limitations lead to a moderate success rate of around 60% [9].

Endodontic surgery has continued to develop into an accurate, biologically-based dependent to nonsurgical root canal treatment since the 1990s. Recent

advancements in endodontic microsurgery include microscopes, ultrasonic instruments, and miniaturized armamentarium, which have enhanced access, visualization, and operative procedures with minimal bevel of root resection, preparation of root end and filling to the depth of 3 to 4 mm. Moreover, biocompatible root-end fillings such as intermediate restorative material (IRM), SuperEBA, and mineral trioxide aggregate (MTA), and miniaturized armamentarium have enhanced tissue responses [2, 10]. These developments in surgical endodontics have tried to minimize trauma and achieve better surgical results. A retrospective study showed that complete healing rate of the modern technique (91.1%) has significantly higher success rate than that for cases by the traditional technique (44.2%) [11]. A 5-year controlled clinical trial revealed that modern microsurgical apicoectomy using piezo-osteotomy showed significantly higher success rate after 1 year (94%) than traditional apicoectomy (67%) [7]. An early meta-analysis reported that these microsurgeries are 1.58 times more successful than traditional surgeries with cumulative success rates of 93.52% after 6 month follow-up [12]. Their long-term success (>4 years, 82.5%) [13] and survival (8.7 years, 74%) [14] are comparable to nonsurgical retreatment. However, long-term cumulative success rates for microsurgeries in cohorts have not been reported.

Success involves resolution of inflammation and regeneration of periodontal ligament and alveolar bone to support normal tooth functions. Several studies have been conducted on bone healing in a primate and lateral incisor, 1st premolar, 2nd premolar and 1st molar, which is a significant factor in determining the success of endodontic microsurgery [15, 16]. The bony defects are filled with a disorganized fibrin-composed coagulum. It is then replaced with granulation tissue consisting of an extracellular matrix generated by fibroblasts, immune cells such as neutrophils,

and macrophages. Abundant vascularization is a key factor which leads to the substitution of necrotic tissue by vital bone tissue [17]. Trabecular bone growth occurs on the endosteal surfaces from the periphery to the middle of the excisional wound at the bone front. Similarly, blood vessel endothelium pericytes, undifferentiated mesenchymal cells, and fibroblast-like cells differentiate into osteoblasts and form small bone islands. At that point, these island broaden and include metabolically active osteocytes in new islands of woven bone. New bone formation is evident approximately 14 days after surgery [18].

Active osteoblasts can be located at these woven bone surfaces with laying osteoid which is the unmineralized framework stored by the osteoblasts, and that will be mineralized. Finally, the woven bone will go through lamellar compaction, and it prompts remodeling into lamellar trabecular bone. The woven bone will grow toward the connective tissue underlying the mucoperiosteum at the surgical site. Trabeculae are larger and denser at 8 weeks after surgery, and osteoblasts are less active [5]. Within 16 weeks of surgery, the osseous defect is normally filled with bone tissue [5]. At the resected end of the root, cementum will be placed by apposition, and the PDL will be reestablished [19]. New PDL fibers show a functional realignment approximately 8 weeks after surgery that includes reorientation of strands opposite to the resected root end surface, reaching out from the recently formed cementum to the woven bone trabecular [20, 21].

To identify the prognostic factors affecting success, retrospective studies have evaluated age, sex, tooth position, obturation length, preoperative lesion size, apical sealing material, and coronal restorations [22-26]. The height of buccal bone plate had a significant effect on the successful outcome in the prospective study about the influence of bone tissue deficiency on the prognosis of endodontic microsurgery [27].

A meta-analysis found that cases without preoperative pain or signs, with dense obturations, with periapical lesions smaller than 5 mm, and operated through microscope were significantly more likely to heal [28]. In a prospective study of 788 surgeries with 4–10 year follow-up, patients over 45 years old, teeth with inadequate obturation length, and crypt sizes smaller than 10 mm had better clinical outcomes [29]. In a 5-year longitudinal study, interproximal bone levels and root-end filling material were significant prognostic factors [30].

Previous studies that relied on short-term follow-up may have overestimated success and failed to account for rates of regression. Longitudinal assessments revealed an 8% reduction in healing rates from 1 (83.8%) to 5 years (75.9%) [30]. Similarly, 6.7% of short-term surgical successes had reverted to failures on long-term follow-up [31]. Additionally, most studies are based on inconsistent surgical databases that include various root-end filling materials, multiple operators, and disparities in surgical devices including microscopes and ultrasonics. Such variations in materials and techniques confound the analysis of prognostic factors.

This study's purpose was to assess long-term outcomes in cohort endodontic microsurgeries and identify their association with prognostic factors. A cohort of cases performed by a sole practitioner utilizing consistent treatment protocols in teeth that were retained and functional for over 5 years were retrospectively analyzed for healing outcomes to identify the prognostic factors affecting success and survival.

2. Material and Method

2.1. Case Selection

Approval was obtained from the Seoul National University Dental Hospital (SNUDH) Institutional Review Board (ERI19041). Records of patients who underwent endodontic microsurgery performed by a single endodontist between 2006 and 2015 in the Department of Conservative Dentistry at SNUDH and were followed up for at least 5 years were reviewed. Teeth extracted within a 5-year follow-up period were included as failures.

2.2. Treatment Protocol

All surgeries were performed by the same endodontist (K.K.) using a microscope (Carl Zeiss, Oberkochen, Germany) and consistent protocols. Following local anesthesia (2% lidocaine, 1:100,000 epinephrine), a full-thickness mucoperiosteal flap was reflected with a P24G periosteal elevator (Hu-Friedy, Chicago, IL, USA). Osteotomy was performed with a #4 round bur and high speed handpiece to access the root apex, which was resected (≤ 3 mm) with minimal or no bevel. Granulomatous tissues were curetted and hemostasis obtained with 0.1% epinephrine (Bosmin; Jeil, Seoul, Republic of Korea) and ferric sulfate (Astringedent; Ultradent Products, South Jordan, UT, USA). Root-end surfaces were stained with methylene blue and examined with a micro-mirror to identify cracks, isthmuses, and accessory canals. Apical canal (s) were enlarged deeply (≥ 3 mm) with ultrasonics (B&L, Ansan, Republic of Korea) and filled with ProRoot MTA (Dentsply Sirona, Tulsa, OK, USA) by micro-pluggers (B&L). Flaps were secured with 5 × 0 coated Vicryl (ETHICON, Bridgewater, NJ and Cincinnati, OH, USA) sutures for 5–7 days and postoperative

dressings placed the next day. Antibiotics, analgesics, digestive aids, and 0.2% chlorhexidine gluconate gargle (Hexamedin; Bukwang Phar Co, Ansan, Korea) were prescribed for 5 days.

2.3. Clinical and Radiographic Evaluation

Patients were recalled every 6 months for clinical and radiographic examinations. Signs or symptoms of discomfort to palpation and percussion, or biting, tooth mobility, and sinus tracts were recorded. Periapical radiographs were assessed at least annually, and final evaluations based on at least 5-year follow-ups performed independently by two examiners according to Molven's criteria [32, 33]. Each case was assessed as one of the following (Figure 1): 1. Complete healing; 2. Incomplete healing; 3. Uncertain healing; 4. Unsatisfactory healing.

1. Complete healing: the periodontal space has reformed around the apex, which is less than twice the width of the noninvolved parts of the root; complete bone repair with no apical periodontal space.
2. Incomplete healing: the rarefaction has decreased or remained and is characterized by one or more of the following findings: irregular periphery of the rarefaction, the rarefaction is located asymmetrically around the apex, the connection of the rarefaction with the periodontal space is angular, and isolated scar tissue in the bone is observed with these findings.
3. Uncertain healing: rarefaction has decreased in size, and is accompanied by one or more of the following findings: the rarefaction is larger than twice the width of the periodontal space; it has a circular or semicircular periphery; it is located symmetrically around the apex as a funnel-shaped extension of the periodontal space; and bony structures are discernible within the bony cavity.

4. Unsatisfactory healing: the rarefaction has enlarged or has remained unchanged.

Treatment outcomes were based on clinical and radiographic findings. In the absence of clinical signs or symptoms of apical periodontitis, radiographic evidence of complete or incomplete healing was classified as a successful outcome. Conversely, the presence of any clinical signs or symptoms of apical periodontitis and/or radiographic evidence of uncertain or unsatisfactory healing, was classified as a failure. For the computation of survival analysis, teeth that had been extracted within 5 years of follow-up were classified as failures.

2.4. Evaluation Factors

For each tooth that had received endodontic microsurgery, their clinical and radiographic records revealed 28 clinical variables. Based on the variables obtained through medical records and radiographs, the variables thought to have an effect on the prognosis were investigated. These variables included preoperative, operative, and postoperative factors as follows [24, 34].

1. Preoperative: age, sex, tooth position, jaw, hypertension, diabetes, osteoporosis, length of canal filling (within 2mm from apex, more than 2mm from apex, over filling), canal filling density (void or none void), periodontal disease (apical involvement or not) , preoperative pain, percussion, mobility, palpation, bite, swelling, sinus tract, root resorption, lesion size (5×5 mm), resurgery, post
2. Operative: anatomic involvement, bone graft, collagen membrane
3. Postoperative: the presence of crown restoration at follow-up, bridge abutment, removable partial denture (RPD) abutment, opposite tooth to implant

2.5. Statistical Analysis

Outcomes were assigned to binary variables: success/failure and survival/nonsurvival. All factors were analyzed by Pearson's chi-square or Fisher's exact test, and potential prognostic factors were analyzed with a multiple logistic regression. Basically, chi-square test was performed, and Fisher's test was used when the number of cells with an expected frequency of 5 or less were less than 25%. In the case of Pearson's chi-square or Fisher's exact test, the influence of other variables cannot be considered together because it is an univariate analysis that only sees the effect of one factor on the result. Therefore, a multivariate analysis that can control the influence of other variables is required, so multiple logistic regression was performed. Survival times were calculated from the date of microsurgery to the date of extraction or follow-up confirmation of retention. Cumulative survival rates were calculated by the Kaplan–Meier method. Factors affecting survival rate were evaluated by Cox proportional hazards regression analysis. All statistical analyses were performed with SPSS v25.0 software (IBM Corp. Armonk, NY, USA) and $\alpha = 0.05$.

3. Result

Of 652 cases in the cohort, 225 (34.5%) could be recalled to assess outcomes and prognostic factors (Table 1). The mean follow-up was 90.4 months (7.5 years); range of 60–168 months (5–14 years). During surgery, the mean age was 47.8 years, with nearly equal numbers over and under 50 years. Females (162, 72%) outnumbered males (63, 28%). Most were maxillary anterior teeth (82, 36.4%), followed by

maxillary premolars (59, 26.2%), maxillary (31, 13.3%) and mandibular (25, 11.6%) molars, and mandibular anterior teeth (15, 6.7%) and premolars (13, 5.8%).

For postoperative radiographic interpretation, the inter-rater reliability was high (Cohen's Kappa coefficient 0.90). There were 148 (66%) completely healed and 33 (14%) incompletely healed cases that accounted for the 80.5% overall success rate (Table 2). There were 37 (16%) unsatisfactory and 7 (4%) uncertain healings. Of 37 unsatisfactory healings, 36 had been extracted within a 5-year follow-up (Table 3) for crown fractures from caries (19%), periodontal disease (19%), or persistent pain (19%).

Chi-square and Fisher's exact tests for univariate analysis found significant differences in success rates associated with age ($P = 0.041$), tooth position ($P = 0.023$), periodontal disease ($P = 0.002$), tooth mobility ($P = 0.017$), crown restorations ($P < 0.001$), RPD abutments ($P = 0.007$), and sinus involvement ($P = 0.029$) (Table 4).

Logistic regression as multivariate analysis was performed with the initial model included potential prognostic factors which were significant in chi-square or Fisher's exact test (age, tooth position, periodontal disease, tooth mobility, crown restoration, RPD). Subsequently, logistic regression analysis found tooth mobility and RPD abutments to be insignificant ($P > 0.05$), so they were excluded to improve the model fitness (R-square). Outcomes were associated with tooth position (OR = 5.405, (95% CI, 1.663–17.571; $P = 0.005$)) and periodontal disease (OR = 0.170, (95% CI, 0.032–0.900; $P = 0.037$)) as preoperative, crown restoration (OR = 10.232, (95% CI, 3.374–31.024; $P < 0.001$)) as postoperative, and anatomic involvement (OR = 0.187, (95% CI, 0.035–0.994; $P = 0.049$)) as operative factors (Table 5).

Kaplan–Meier survival analysis showed an 83.5% 5-year survival rate, with mean

time until extraction 142.4 months (95% CI, 135.0–150.0) (11.0 ± 0.3 years) regardless of the reason (Figure 2). Cox proportional hazards regression of significant factors from univariate analysis (Table 6) confirmed that survival was significantly affected by tooth position (hazard ratio (HR) = 0.254, (95% CI, 0.098–0.654; $P = 0.005$)) and percussion (HR = 2.078, (95% CI, 1.064–4.058; $P = 0.032$)) among preoperative, crown restorations (HR = 0.166, (95% CI, 0.073–0.376; $P < 0.001$)) and RPD abutments (HR = 8.813, (95% CI, 1.914–40.576; $P = 0.005$)) among postoperative, and sinus involvement (HR = 8.813, (95% CI, 1.378–11.900; $P = 0.009$)) among operative factors (Table 7). Anterior teeth were more likely to survive, whereas RPD abutments, and teeth with percussion pain or sinus involvement were less likely.

4. Discussion

This cohort's overall healed rate was 80.5%, which is higher than the Toronto Study's 74% for 4–10 years [29], or 76% in 5 years longitudinally [30]. In this study, teeth extracted due to caries and periodontal problems irrelevant to the surgery were also considered as a failure. Taking this point into account, the actual success rate might be higher. Cohort effects aside, higher success may have been due to longer follow-ups. Molven et al. proposed that uncertain cases after 1-year follow-up are unpredictable and need longer recalls [32, 33]. Studies have reported that short-term follow-up success rates were 3.5–8.5% lower than for 4-years or longer [30, 35]. Additionally, advanced microsurgical tools and techniques including microscopy, ultrasonics, and biocompatible root-end filling materials may have contributed to success. The overall 5-year survival rate was 83.5%, which is similar to that of a

smaller recent study [36]. Potential survival rates were even higher if unrelated extractions were excluded.

This retrospective cohort study found that tooth position, crown restorations, periodontal disease, and sinus involvement significantly affected long-term outcomes for endodontic microsurgery. Identifying prognostic factors will enable treatment planning and case selection.

Anterior teeth had the highest success, followed closely by premolars and molars. Differences between anterior teeth and molars were significant ($OR = 5.405$, $P = 0.005$), whereas differences between anterior teeth and premolars were not. Similarly, previous studies showed higher anterior teeth success [24, 34, 37, 38], attributed to ease of surgical access and less complex root canal anatomy than molars [28].

Teeth with adequate coronal restorations at follow-up were ten times more likely to have healed than those without restorations. Furthermore, teeth with full veneer crowns had higher success than those with only composite resins. Similarly, others showed that adequate coronal restorations significantly improved outcomes [23]. Unlike full-crown restorations, composite resins alone may increase endodontically treated teeth's susceptibility to vertical root fracture [39].

Teeth with combined periodontal–endodontic lesions had significantly less success ($OR = 0.170$, $P = 0.032$), which is consistent with previous studies [34, 40]. Periodontitis causes alveolar bone loss, periodontal recession, apical migration of gingival epithelial cells, and long junctional epithelium, which may compromise healing [25]. They can develop a microbial pathway to the apical region following microsurgery [40]. Therefore, the prognosis for these teeth will depend on both periodontal treatments and endodontic microsurgery [41].

Cases where the periapical lesion had involved the maxillary sinus had much

lower success (42.9%). Logistic regression showed that this anatomical involvement significantly reduced the prognosis for microsurgery ($OR = 0.187$, $P = 0.035$). Lesions involving the sinuses pose microsurgical challenges including difficult access, root-end and granulomatous tissue removal, and the risk of damage and debris into the sinuses [42]. Subsequent healing will likely involve remodeling of the sinus membrane. Maxillary sinus involvement is a factor that has not been discussed in other studies that analyzed the prognosis of endodontic microsurgery. Ericson found no difference in endodontic surgery outcomes between groups with and without oroantral communication, but this is the result of traditional endodontic surgery using conventional methods such as amalgam filling [43]. In this study, only the cases in which the lesion was related to the cortical bone destruction of the sinus floor were recorded on the postoperative chart, or the cortical bone destruction of the maxillary sinus was clearly visible on the CBCT were included, and only 7 cases were related. Therefore, care should be taken for interpretation, and it is necessary to analyze more detailed analysis in the future by classifying whether sinus is related or not based on more accurate criteria through CBCT images .

Patients under 50 years of age had higher success (85.6%) than those over 50 (74.8%). However, these differences were not significant when logistic regression accounted for other variables. Younger patients may have better healing capacity and less periodontal disease [1], but long-term follow-ups reduced their significance. Previous studies have reported that age and sex did not significantly affect outcomes [24, 36, 37, 44, 45].

Interestingly, a history of prior apical surgery on the root did not significantly affect the success of additional microsurgery. Along with other studies [46-49], this shows that the prognosis is not dependent on prior surgery but on identifying and

resolving the cause of apical periodontitis. Teeth fracture resistances (von Mises stress) are not significantly reduced until over 6 mm of root-end resections [50]. Thus, re-surgery can be an effective treatment options for prior inadequate root-end resections and fillings [51].

Systemic conditions including hypertension, diabetes, and osteoporosis did not significantly affect surgical success. Similarly, systemic diseases may not affect non-surgical endodontics [52]. However, diabetes mellitus can delay periapical healing [53], and diabetics have less success with non-surgical endodontics, especially for teeth with apical periodontitis [52].

Pre-existing pain and pain on percussion, palpation, or biting were insignificant threats to success, as reported by others [37, 38]. In other studies, sensitivity on percussion [54] and preoperative pain [55, 56] were related to success rate. Preoperative mobility diminished success, which was probably due to associated periodontal disease. Similarly, sinus tracts, swellings, root resorption, and lesion size were insignificant. Although others found significant effects for preoperative lesion size [10, 57], long-term follow-ups over 5 years allowed sufficient healing in this study. Similarly, 4-year retrospective [23] and 5-year longitudinal studies [30] found that lesion size had an insignificant effect on success. The 4- to 10-year prospective Toronto study found that lesions smaller than 10 mm were more likely to heal [11]. However, lesions over 10 mm may have been incompletely curetted, leaving residual tissues and persistent infections [58].

Serving as fixed partial denture (bridge) abutments did not affect success. However, serving as RPD abutments significantly reduced success according to chi-square tests. Additional logistic regression analysis found the differences to be insignificant, suggesting an uneven distribution of subsets for these variables. Indeed,

nonsurgical endodontics was reported to have significantly more failures in RPD abutments than single-crown teeth [59].

Cox proportional hazards regression revealed that tooth position, crown restorations, sinus involvement, RPD abutments, and pain on percussion significantly affected survival. Anterior teeth had a significantly higher cumulative survival than molars (Figure 3A). Full-veneer crowns at follow-up significantly increased survival in anterior teeth and posteriors (Figure 4), despite markedly lower occlusal forces in anterior teeth (Figure 4B). Conversely, survival was significantly much lower for cases where the lesion had involved the sinus (Figure 3B). All these results were consistent with the logistic regression analysis of prognostic factors for success.

Pain on percussion was insignificant for success, but significant in Cox proportional hazards regression for survival (Figure 3C). This was likely due to seven extractions from persistent pain, six of which initially had pain on percussion.

RPD abutments had significantly lower survival following surgery (Figure 3D), which is similar to their lower survival following non-surgical treatment. Additional mechanical stresses imposed on abutments may increase their risk of fracture [60], and the poor crown-root ratio of abutments undergoing microsurgery accounted for lower survival.

To mitigate the effects of confounding variables, a single cohort of consistent surgical cases was studied. However, the residual effects of confounding post-operative factors may have remained. Some failures may not have been due solely to endodontic therapy but to restorative procedures and the periodontal status of the teeth. In this cohort, 34.5% were recalled and included in the assessment of treatment outcomes and prognostic factors. A review of all available records indicated that

these large numbers of cases were representative of the full cohort. However, theoretically, the missing data may have disproportionately affected the results. Therefore, interpretation of these findings is restricted by the limitations of the study design. Retrospectively, asymptomatic patients may have been less likely to attend follow-up, which may have led to an under-reporting of long-term success. A more rigorous study would be prospective and utilize CBCT with software to precisely digitize three-dimensional healing of periapical lesions [61]. Safi et al. showed that success differed by about 8% when evaluated by CBCT versus periapical radiographs [62].

Despite these limitations, the current study involved long-term (over 5 years) follow-ups of a large number of surgical cases that had been performed by the same surgeon (endodontist) using a consistent protocol. This contrasts with other studies that involved multiple operators and surgical techniques, which may confound the analyses of success rates and survival times.

Furthermore, these improvements in success and survival rates obtained through advanced microsurgical techniques are likely to continue with progressive developments in technology. These advancements may include computerized techniques for surgical access with customized trephine burs [63] and dynamic navigation systems using computer-driven optical positioning devices [64]. Future studies will need to investigate treatment outcomes of these next-generation surgical techniques.

5. Conclusion

This retrospective cohort study had an overall long-term success rate of 80.5% following endodontic microsurgery. Tooth position, crown restorations, periodontal disease, and maxillary sinus involvement affected the prognosis. Anterior teeth and the presence of crown restorations at follow-up were associated with higher long-term success. Maxillary sinus involvement of periapical lesions and combined periodontal–endodontic lesions were associated with lower success. Additionally, Kaplan–Meier survival analyses showed a 5-year survival rate of 83.5%. Tooth position, crown restoration at follow-up, pain on percussion, RPD abutments, and maxillary sinus involvement had significant effects on survival. Collective evidence supports endodontic microsurgery as a successful and reliable treatment option for treating apical pathosis and maintaining natural teeth.

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Tables and Figures

Table 1. Study sample

Descriptor	Number	Proportion (%)
Age (years)		
≤ 50	118	52.4
> 50	107	47.6
Sex		
Male	63	28.0
Female	162	72.0
Jaw		
Maxilla	171	76.0
Mandible	54	24.0
Tooth position		
Maxillary Anterior Teeth	82	36.4
Mandibular Anterior Teeth	15	6.7
Maxillary Premolar	59	26.2
Mandibular Premolar	13	5.8
Maxillary Molar	31	13.3
Mandibular Molar	25	11.6

Table 2. Healing outcomes, success, and survival rates.

Outcome	<i>N</i>	Proportion (%)
Complete healing	148	65.8
Incomplete healing	33	14.7
Uncertain healing	7	3.1
Unsatisfactory healing ^a	37	16.4
Success	181	80.5
5-year survival rate ^b		83.5
10-year survival rate ^b		83.0

Table 3. Reasons for Extraction

Reason	Number	Proportion (%)
Crown fracture from caries	7	19.4
Root fracture	5	13.9
Periodontal problem	7	19.4
Failure to heal	6	16.7
Persistent pain	7	19.4
Unknown	4	11.1
Total extractions	36	100

Table 4. Success rates analyzed (chi-square or Fisher's exact test) for potential prognostic factors.

Variable	Success		Failure		Chi-square	P-Value ^a
	N	(%)	N	(%)		
Age					4.181	0.041 *
>50	80	74.8	27	25.2		
≤50	101	85.6	17	14.4		
Sex					1.898	0.168
Male	47	74.6	16	25.4		
Female	134	82.7	28	17.3		
Jaw					0.922	0.337
Maxilla	140	81.9	31	18.1		
Mandible	41	75.9	13	24.1		
Tooth position					7.51	0.023*
Anterior Teeth	82	84.5	15	15.5		
Premolar	61	84.7	11	15.3		
Molar	38	67.9	18	32.1		
Hypertension					3.373	0.066
Hypertensive	28	70.0	12	30.0		
Normotensive	153	82.7	32	17.3		
Diabetes					Fisher's exact	0.383
Diabetes	6	66.7	3	33.3		
Normal	175	81.0	41	19.0		

Osteoporosis					Fisher's exact	0.481
	Osteoporosis	2	66.7	1	33.3	
	Normal	179	80.6	43	19.4	
Length of canal filling					1.374	0.503
	Overfilling	11	91.7	1	8.3	
	Underfilling	64	78.0	18	22.0	
	Normal	98	81.7	22	18.3	
Canal filling density					0.46	0.498
	Void	69	83.1	14	16.9	
	No void	104	79.4	27	20.6	
Periodontal- disease					Fisher's exact	0.002 **
	Involvement	3	33.3	6	66.7	
	Not-involved	178	82.4	38	17.6	
Pain					0.239	0.625
	Pain (+)	79	79.0	21	21.0	
	Pain (–)	102	81.6	23	18.4	
Percussion					1.694	0.193
	Present	71	76.3	22	23.7	
	Absent	110	83.3	22	16.7	

Mobility						5.717	0.017 *
	Present	23	65.7	12	34.3		
	Absent	158	83.2	32	16.8		
Palpation						1.19	0.275
	Present	33	86.8	5	13.2		
	Absent	148	79.1	39	20.9		
Bite						0.232	0.63
	Present	20	76.9	6	23.1		
	Absent	161	80.9	38	19.1		
Swelling						<0.001	0.985
	Present	29	80.6	7	19.4		
	Absent	152	80.4	37	19.6		
Sinus tract						1.808	0.179
	Present	33	73.3	12	26.7		
	Absent	148	82.2	32	17.8		
Root resorption						Fisher's exact	1
	Present	15	83.3	3	16.7		
	Absent	166	80.2	41	19.8		
Crown restoration at follow-up						13.824	< 0.001 **
	Crown	158	84.9	28	15.1		
	None	23	59.0	16	41.0		

Bridge							
abutment						0.001	0.976
tooth							
	Yes	25	80.6	6	19.4		
	None	156	80.4	38	19.6		
Tooth							
opposing						Fisher's	1
implant						exact	
	Opposing		100.				
		3		0	0.0		
	implant		0				
	None	178	80.2	44	19.8		
RPD						Fisher's	
abutment						exact	0.007 **
	Yes	0	0.0	3	100.		
					0		
	None	181	81.5	41	18.5		
Post						1.316	0.251
	Present	48	85.7	8	14.3		
	Absent	133	78.7	36	21.3		
Sinus						Fisher's	
involvement						exact	0.029*
	Yes	3	42.9	4	57.1		
	None	178	81.7	40	18.3		

Lesion size					1.391	0.238
	>5 × 5 mm	24	88.9	3	11.1	
	≤ 5 x 5 mm	157	79.3	41	20.7	
Bone graft					Fisher's exact	0.077
	Bio-Oss	13	100. 0	0	0.0	
	None	168	79.2	44	20.8	
Membrane					Fisher's exact	0.211
	Collagen	9	100. 0	0	0.0	
	None	172	79.6	44	20.4	
Re-surgery					Fisher's exact	0.707
	Re-surgery	9	75.0	3	25.0	
	First surgery	172	80.8	41	19.2	

RPD, removable partial denture; ^a *P*-value for Chi-square test or Fisher's exact test.

Table 5. Results of logistic regression model.

Variables	Beta	SE	P-Value ^a	OR	95% Confidence Interval	
					Lower	Upper
					Limit	Limit
Tooth position						
Anterior Teeth vs. Molar	1.687	0.601	0.005 **	5.405	1.663	17.571
Anterior Teeth vs. Premolar	0.843	0.505	0.095	2.324	0.864	6.249
Age group						
≤50 vs. >50	−0.460	0.396	0.245	0.631	0.290	1.372
Periodontal disease						
Involvement vs. None	−1.772	0.850	0.037 *	0.170	0.032	0.900
Crown at follow-up						
Crown vs. None	2.325	0.566	0.000 **	10.232	3.374	31.024
Maxillary sinus involvement						
Involvement vs. None	−1.675	0.852	0.049 *	0.187	0.035	0.994

SE, standard error; OR, odds ratio; ^a *P*-value for logistic regression.

Table 6. Results of the univariate analysis of survival by log rank (Mantel-Cox) test

Variable	Event (n) /total	Chi-square	P-value ^a
Age		4.452	0.035
> 50	25/107		
≤ 50	15/118		
Sex		0.003	0.955
Male	11/63		
Female	29/162		
Jaw		0.235	0.628
Maxilla	29/171		
Mandible	11/54		
Tooth position		5.685	0.058
Anterior Teeth	12/97		
Premolar	13/72		
Molar	15/56		
Hypertension		2.184	0.139
Hypertensive	10/40		
Normotensive	30/185		
Diabetes		0.117	0.732
Diabetes (+)	2/9		
Diabetes (-)	38/216		
Osteoporosis		0.724	0.395
Osteoporosis	1/3		
Normal	39/222		

Length of canal filling			2.965	0.227
	Overfilled	1/12		
	Underfilled	19/82		
	Adequate	18/120		
Canal filling density			1.719	0.190
	Voids	11/83		
	No voids	27/131		
Periodontal disease			7.019	0.008**
	Involvement	4/9		
	Normal	36/216		
Pain			0.235	0.627
	Present	19/100		
	Absent	21/125		
Percussion			5.221	0.022*
	Present	23/93		
	Absent	17/117		
Mobility			5.357	0.021*
	Present	11/35		
	Absent	29/190		
Palpation			0.508	0.476
	Present	5/38		
	Absent	35/187		

Bite		0.811	0.368
	Present	6/26	
	Absent	34/199	
Swelling		0.021	0.885
	Present	6/36	
	Absent	34/189	
Sinus tract		< 0.001	0.992
	Present	8/45	
	Absent	32/180	
Root resorption		1.851	0.174
	Present	1/18	
	Absent	39/207	
Restoration at follow-up		7.754	0.005**
	Crown	27/186	
	Other	13/39	
Bridge abutment		0.045	0.832
	Bridge abutment	6/31	
	None	34/194	
Tooth opposing implant		0.567	0.452
	Opposing implant	0/3	
	No	40/222	

RPD abutment		7.346	0.007**
	Yes	2/3	
	No	38/222	
Post		0.002	0.965
	Present	10/56	
	Absent	30/169	
Anatomic involvement		11.888	0.001**
	Maxillary Sinus	4/7	
	Normal	36/218	
Lesion size		1.988	0.159
	> 5 x 5 mm	2/27	
	≤ 5 x 5 mm	38/198	
Bone graft		2.417	0.120
	Bio-Oss	0/13	
	None	36/212	
Membrane		2.559	0.110
	Collagen Membrane	0/9	
	None	40/216	
Re-surgery		0.590	0.442
	Re-surgery	3/12	
	First surgery	37/213	

Abbreviations: RPD, removable partial denture.

^a P value for log rank (Mantel-Cox) test.

Table 7. Results of the multivariate Cox proportional hazard regression model

	Beta	SE	P-value ^a	HR ^b	95% Confidence Interval	
Variables					Lower Limit	Upper Limit
Tooth position						
Anterior Teeth vs Molar	-1.372	0.483	0.005**	0.254	0.098	0.654
Anterior Teeth vs Premolar	-0.453	0.386	0.241	0.636	0.298	1.355
Percussion	0.732	0.341	0.032*	2.078	1.064	4.058
Crown at follow-up	-1.796	0.418	0.000**	0.166	0.073	0.376
Anatomic involvement	1.399	0.550	0.011*	4.049	1.378	11.900
Removable partial denture abutment	2.176	0.779	0.005**	8.813	1.914	40.576

Abbreviations: SE, standard error; HR, hazard ratio; RPD, removable partial denture

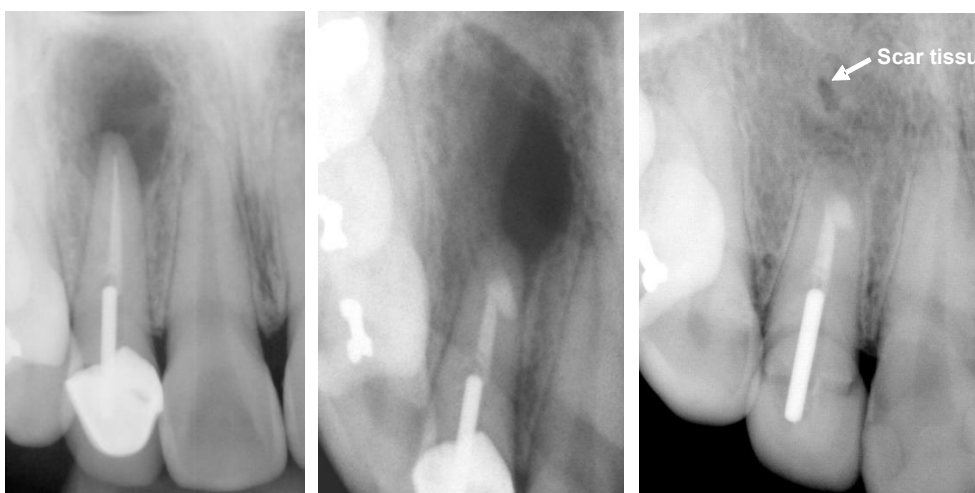
^a P value for multivariable-adjusted Cox proportional hazards regression.

^b Cox proportional hazards regression model adjusted for tooth position, percussion, crown at follow-up, sinus involvement, and RPD abutment. Age, periodontal disease and mobility were excluded by backward elimination using likelihood ratio.

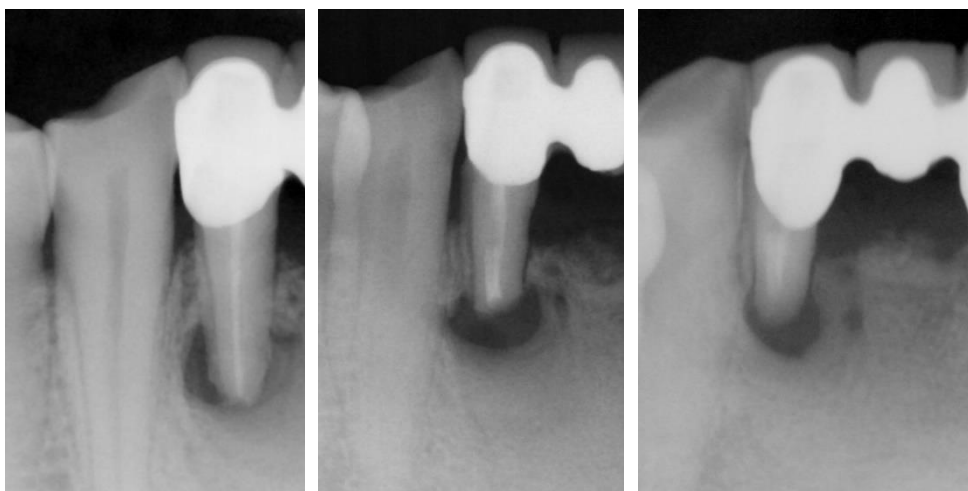
(A) Complete healing



(B) Incomplete healing



(C) Uncertain healing



(D) Unsatisfactory healing

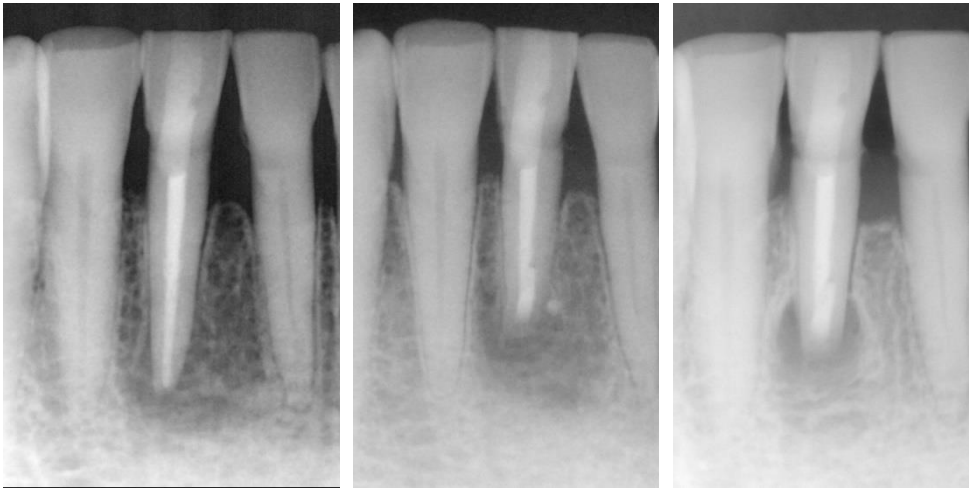


Figure 1. Periapical radiographs demonstrating healing outcomes. (A) Complete healing; preoperative (left), postoperative (center), and 14-year follow-up (right) radiographs showing complete healing of #15 and #16. (B) Incomplete healing; preoperative (left), postoperative (center), and 14-year follow-up (right) radiographs showing incomplete healing (scar tissue) of #12. (C) Uncertain healing; preoperative (left), postoperative (center), and 8-year follow-up (right) radiographs showing uncertain healing of #42. (D) Unsatisfactory healing; preoperative (left), postoperative (center), and 4-year follow-up (right) radiographs showing unsatisfactory healing of #41.

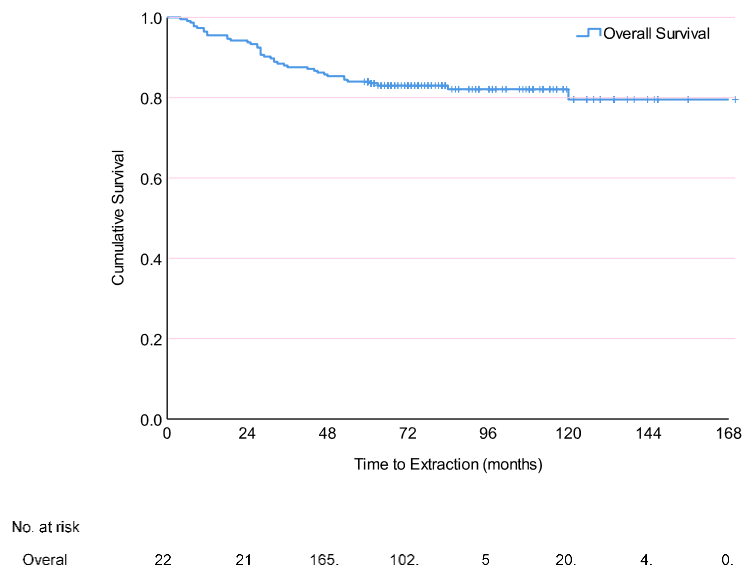
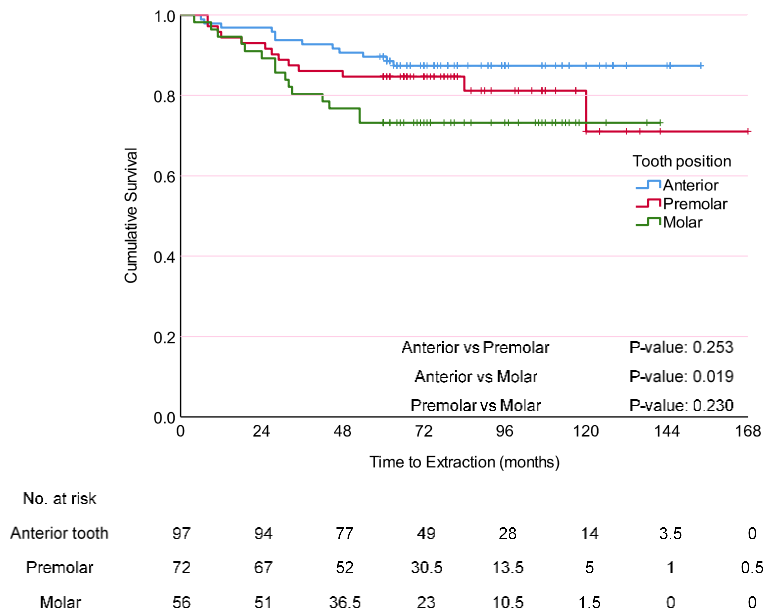


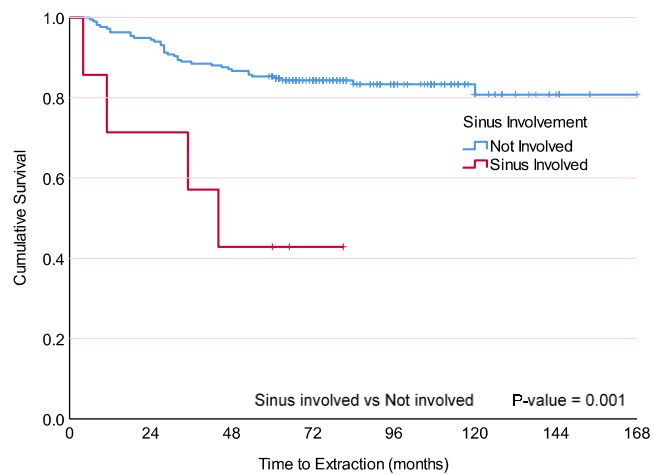
Figure 2. Kaplan–Meier survival analysis of endodontic microsurgery teeth ($n = 225$).

Figure 3. Kaplan-Meier survival analysis of teeth following endodontic microsurgery (n = 225), according to potential prognostic factors.

The number of teeth at risk are presented below the x-axis. P-values are based on the log-rank test. Time 0 on the x-axis (i.e., beginning of teeth being at risk) is date of endodontic microsurgery.

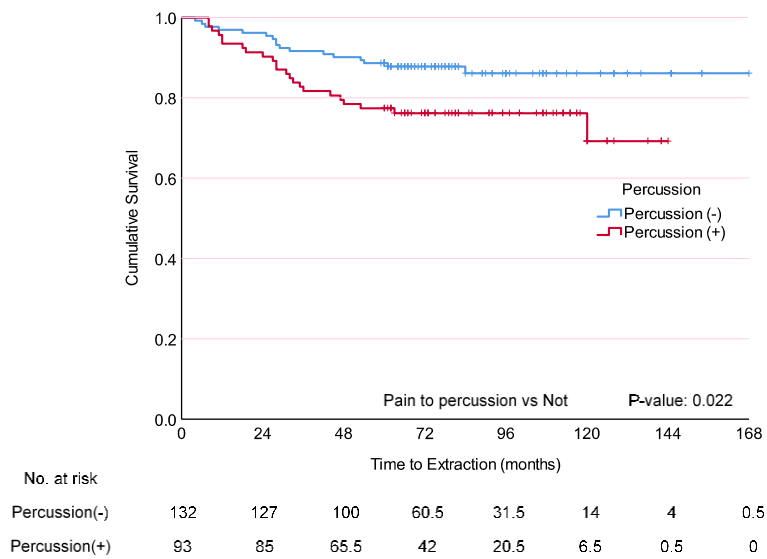


A. Tooth position (Anterior Teeth vs Premolar vs Molar): There were 12 extractions in 97 anterior teeth; there were 13 extractions in 72 premolar teeth; there were 15 extractions in 56 molar teeth. Mean survival time was 139.0 months (131.0 - 149.7 months) for anterior teeth, 138.0 months(122.6 - 153.4 months) for premolar teeth, and 111.6 months(98.3 - 124.9 months) for molar teeth

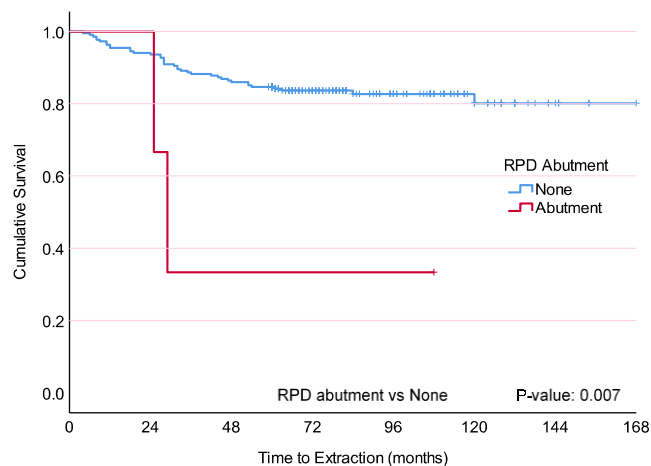


No. at risk								
Not Involved	218	207	163.5	102	52	20.5	4.5	0.5
Sinus Involved	7	5	2	0.5	0	0	0	0

B. Sinus involvement (Involved or not): There were 4 extractions in 7 sinus involved teeth; there were 36 extractions in 218 non-involved teeth. Mean survival time was 48.1 months (25.1 – 71.2 months) for sinus involved teeth, 144.2 months (137.0 – 151.5 months) for non-involved teeth.



C. Percussion (pain or not): There were 17 extractions in 132 percussion (-); there were 23 extractions in 93 percussion (+). Mean survival time was 149.7 months (141.5 – 157.9 months) for percussion (-), 114.9 months (104.5 – 125.3 months) for percussion (+).



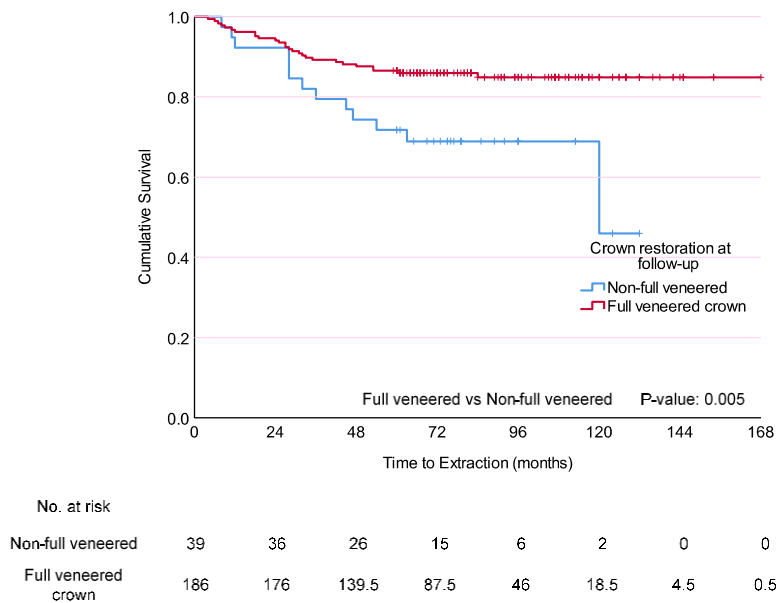
No. at risk								
None	222	209	164.5	101.5	51.5	20.5	4.5	0.5
Abutment	3	3	1	1	0.5	0	0	0

D. RPD abutment (abutment or none): There were 2 extractions in 3 RPD abutment; there were 38 extractions in 222 non-abutments. Mean survival time was 54.0 months (10.8 – 97.2 months) for RPD abutment, 143.3 months (136.0 – 150.6 months) for non-abutment.

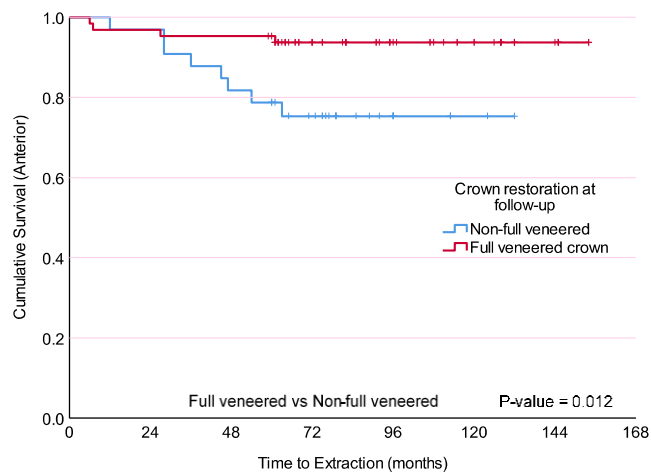
Abbreviation: RPD, removable partial denture.

Figure 4. Kaplan-Meier survival analysis of teeth following endodontic microsurgery, according to restoration status and tooth position.

The number of teeth at risk are presented below the x-axis. P-values are based on the log-rank test. Time 0 on the x-axis (i.e., beginning of teeth being at risk) is date of endodontic microsurgery.

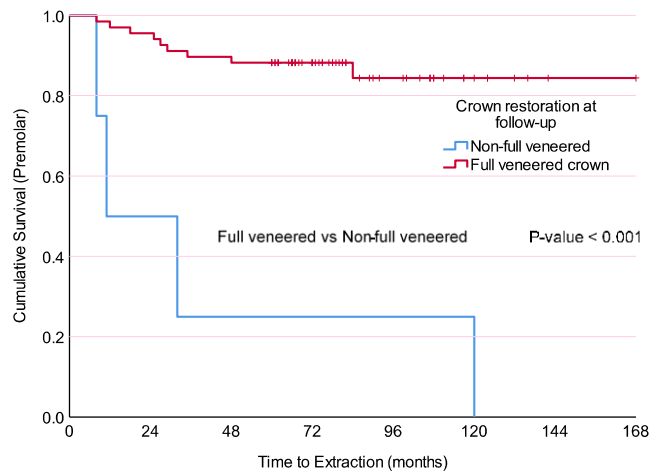


A. Crown restoration at follow-up (Overall teeth, Full veneered vs Non-full veneered): Overall survival analysis regarding to restoration status at follow-up. There were 27 extractions in 186 full veneered teeth; there were 13 extractions in 39 non-full veneered teeth. Mean survival time was 147.3 months (140.1 - 154.6 months) for full veneered teeth, 98.5 months (83.6 - 113.3 months) for non-full veneered teeth.



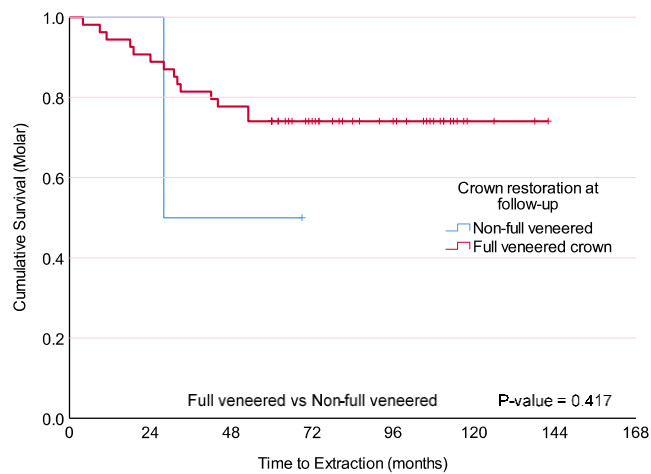
No. at risk								
Non-full veneered	33	32	24.5	14	5	1	0	0
Full veneered crown	64	62	52.5	35	23	13	3.5	0

B. Crown restoration at follow-up (Anterior teeth, Full veneered vs Non-full veneered): Survival analysis of anterior teeth regarding to restoration status at follow-up. There were 4 extractions in 64 full veneered teeth; there were 8 extractions in 33 non-full veneered teeth. Mean survival time was 145.9 months (138.0 - 153.7 months) for full veneered teeth, 109.2 months (95.3 - 123.1 months) for non-full veneered teeth.



No. at risk								
Non-full veneered	4	2	1	1	1	1	0	0
Full veneered crown	68	65	51	29.5	12.5	4	1	0.5

C. Crown restoration at follow-up (Premolar teeth, Full veneered vs Non-full veneered): Survival analysis of premolar teeth regarding to restoration status at follow-up. There were 9 extractions in 68 full veneered teeth; there were 4 extractions in 4 non-full veneered teeth. Mean survival time was 148.0 months (135.6 - 160.3 months) for full veneered teeth, 42.8 months (0.0 - 94.3 months) for non-full veneered teeth.



No. at risk								
Non-full veneered	2	2	0.5	0	0	0	0	0
Full veneered crown	54	49	36	23	10.5	1.5	0	0

D. Crown restoration at follow-up (Molar teeth, Full veneered vs Non-full veneered): Survival analysis of molar teeth regarding to restoration status at follow-up. There were 14 extractions in 54 full veneered teeth; there were 1 extraction in 2 non-full veneered teeth. Mean survival time was 112.6 months (99.2 - 126.0 months) for full veneered teeth, 48.5 months (20.1 - 76.9 months) for non-full veneered teeth.

요약(국문초록)

이 연구의 목적은 미세 치근단 수술의 장기적인 결과를 분석하고 예후인자와의 연관성을 확인하는 것이다. 이 연구는 후향적으로 검토한 연구로써, 미세 치근단 수술을 받은 후 최소 5년이상 주기적인 추적 관찰을 통해 임상 및 방사선 기록을 가진 케이스를 대상으로 하였다. 결과에 영향을 미치는 예후인자들을 식별하기 위해 Pearson 카이-제곱 테스트 및 로지스틱 회귀분석과 생존분석 ($\alpha = 0.05$) 을 통해 생존 및 치유 상태와 해당 케이스의 특성을 분석하였다. 코호트의 652 건 중 225 건 (34.5 %) 이 포함되었으며, 평균 추적 기간은 90.4 개월 (95% CI, 60-168개월) 이었다. 장기적 성공률은 80.5 %, 5년 생존율은 83.5 %였다. 로지스틱 회귀분석결과, 구치부보다는 전치부 (OR = 5.405, (95 % CI, 1.663-17.571; P = 0.005)), 전장관 수복물이 있는 치아 (OR = 10.232, (95 % CI, 3.374-31.024, P <0.001)) 에서 높은 성공률을 보였다. 이와 반대로 치주질환 (OR = 0.170, (95 % CI, 0.032-0.900, P = 0.037)) 및 상악동 침범 (OR = 0.187, (95 % CI, 0.035-0.994, P = 0.049)) 이 있는 경우 더 낮은 성공률을 보였다. 따라서 이번 연구를 통해 치아 위치, 전장관 수복,

치주질환 및 상악동 침범이 주요 예후인자들로 확인되었다. 또한 Kaplan-Meier 생존 분석에서는 5 년 생존율이 83.5 %로 나타났으며, 치아 위치, 전장관 수복, 타진에 통증, RPD 지대치 및 상악동 침범이 생존에 상당한 영향을 미치는 것으로 나타났다. 이러한 결과들은 미세 치근단 수술이 치근단 병소를 치유하고 자연치아를 보존하는데 있어서 장기적으로 매우 양호한 결과를 가져옴을 보여준다.

주요어 : 코호트 연구, 미세 치근단 수술, 장기적 결과, 예후인자, 성공률, 생존율

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