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ORIGINAL ARTICLE

Multivariate outcome evaluation of furcation-involved molars treated with non-surgical mechanical therapy alone or combined with open flap debridement: A retrospective study

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Abstract

Background: This retrospective study assessed the effect of non-surgical and surgical mechanical therapy for furcation-involved molars.

Methods: Furcation defects treated and followed for at least 1 year were selected. Data relative to the clinical outcomes were recorded. The immediate (3- to 6-month) clinical outcomes and the long-term survival of the treated molars were assessed. The potential variables influencing the treatment outcomes through multi-level regression analysis, and Cox Proportional-Hazards Models were also analyzed.

Results: One hundred and eighty-four molars were included with an average follow-up of 7.52 years. At the 3- to 6-month re-evaluation 1.39 ± 0.99 mm pocket depth reduction, 0.88 ± 1.29 mm clinical attachment gain, and a 0.51 ± 1.13 mm increase in recession was observed. The 5- and 10-year survival rates were 88.3% and 61.3%, respectively. The horizontal and vertical extent of furcation involvement, baseline probing depth, mucoperiosteal flap elevation, and the frequency of supportive periodontal therapy influenced the clinical outcomes and tooth survival.

Conclusion: Non-surgical and surgical mechanical root debridement is a viable treatment for the management of furcation involved molars with shallow horizontal and vertical components.

KEYWORDS
furcation defect, molar, periodontitis, supportive periodontal therapy, tooth loss

1 | INTRODUCTION

Furcation involvement (FI) has been classified as one of the most important factors determining the complexity of periodontitis in molars.[1] If left untreated, the FI will disseminate in a horizontal pattern towards the interior part of the furcation, [2] as well as in a vertical orientation directed to the apices of the roots,[3] rendering this area challenging to clean during home-care,[4,5] and increasing the risk of tooth loss.[6]

Several strategies have been proposed for the treatment of FI teeth, including but not limited to non-surgical and surgical mechanical debridement, root amputation, tunneling, and regeneration.[7–10] However, these treatments

have their limitations, such as tooth decay after root amputation or tunneling procedures,[9,11] or unpredictable guided tissue regeneration (GTR) treatment outcome.[12–15]

Numerous studies have investigated the long-term effect of mechanical debridement for FI teeth. Nibali and colleagues conducted a systematic review on studies that performed active periodontal therapy (APT) followed by a period of supportive periodontal therapy (SPT) and found that FI doubles the risk of tooth loss for molars 10 to 15 years after.[16] Hirschfeld and Wasserman reported that in patients undergoing APT and followed for a period of 22 years of SPT, 7.1% of the overall included teeth were lost, whereas 31% of FI teeth were not successfully maintained and had to be extracted.[17] While some studies established that FI highly affects tooth survival,[18–20] others found that the horizontal or vertical degree of periodontal tissue loss in the furcation area were a better predictor for the survival of FI teeth. When properly treated, FI teeth with less horizontal or vertical involvement had a similar risk of tooth loss when compared with teeth without FI.[21–23]

Although many studies have evaluated the long-term survival of furcation involved teeth treated with non-surgical and surgical mechanical debridement (APT phase), followed by SPT,[22,24,25] few studies have focused on the clinical outcomes of FI teeth following the APT phase. Nonetheless, evaluating the success of APT is crucial, since a successful APT is essential for long-term maintenance of dentition during SPT.[25,26] In addition, factors that influence the change in clinical outcome following APT (e.g., the furcation defects morphology and baseline clinical parameters, etc.), as well as the overall survival of treated FI molars are essential information to obtain.[17,27]

Therefore, the aims of this study were to evaluate the clinical outcomes and survival of furcation-involved molars treated with non-surgical and surgical mechanical debridement, and to assess potential factors affecting the outcomes.

2 | MATERIALS AND METHODS

2.1 | Study design

The current investigation was designed according to the principles presented in the Helsinki Declaration of 1975, as revised in 2000 for biomedical research involving human patients. The study was approved by the Institutional Review Board for Human Studies, School of Dentistry, University of Michigan, Ann Arbor, MI, (HUM00186895) to be conducted at the Department of Periodontology and Oral Medicine within the same institution.

This retrospective study selected all patients that had undergone APT, including non-surgical (scaling and root planing [SRP]) or surgical (open flap debridement [OFD]) mechanical debridement (excluding resective or regenerative treatment) for furcation defects followed by SPT in the time period between January 1980 and December 2018 at the University of Michigan School of Dentistry, Ann Arbor, Michigan. All paper files and digital charts of patients with furcation involved teeth treated with non-surgical or surgical mechanical debridement were carefully scanned and analyzed by two independent and pre-calibrated investigators as part of previous studies (JM, LT). At every stage, after examining the gathered data, in case of a disagreement, discussion was held by the two reviewers to reach a consensus. If resolution was not possible, a senior author (either HLW or H-LC) was consulted, and their decision was decisive. As no patients were treated as a direct result of this research, the study required no additional informed consent for the included patients. The current research was prepared in compliance with the STROBE guidelines (see Supplementary Table S1 in online *Journal of Periodontology*).

2.2 | Study population

The present study included patients that had at least one tooth with a furcation defect on either a first or second molar undergoing a phase of APT, including non-surgical (SRP) or surgical (OFD) mechanical debridement followed by an SPT phase (a minimum of one SPT/year). To be included in the present study, all subject records must have had at least 1 year of follow-up following the APT completion and must have complete clinical and radiographic data records.

For all the included population, the baseline data were considered as the data collected before the APT phase. APT consisted of oral hygiene instructions followed by supra-gingival and subgingival SRP. Following SRP, all patients presented for a re-evaluation appointment (4 to 6 weeks) during which it was determined whether further surgical therapy, i.e., OFD, was needed. OFD was then undergone when required. Mild tooth recontouring (odontoplasty) was also performed when necessary. Patients that received other surgical treatments such as regenerative therapy, tunneling procedures, root or osseous resection, or tooth extraction were excluded from the study. In addition, molars having >1 furcation defect (e.g., an upper molar having both buccal and mesio-palatal furcation involvement) were excluded from the study, and only molars with one isolated furcation defect were included (through and through Degree 3 FI were considered as a

single furcation defect). Finally, furcation-involved premolars were also excluded.

2.3 | Data collection and classification

The following information were obtained for all qualified patients: 1) patient-related factors (age and sex); 2) medical history (including documentation of smoking and diabetes); 3) location of the treated defect (mandible/maxilla—buccal/lingual, mid-facial/mesio-palatal/disto-palatal); 4) clinical parameters of the furcation defect: probing depth (PD), gingival recession (REC), clinical attachment level (CAL) and horizontal FI at baseline and at the 3- to 6-months re-evaluation appointment; 5) type of intervention during APT (SRP/OFD); 6) odontoplasty (yes/no); 7) follow-up time (until tooth extraction or last maintenance appointment); 8) SPT frequency; 9) baseline and 1-year follow-up radiographs; and 10) endodontic or restorative treatment of the tooth.

2.4 | Study outcomes

2.4.1 | Survival

The primary outcome of this study was to evaluate the survival of the treated teeth. Tooth survival was assessed according to the Kaplan–Meier method. The final follow-up of any treated tooth was the last recorded appointment at the University of Michigan, School of Dentistry. A tooth was considered lost if it was extracted due to periodontal reasons (inadequate periodontal tissue support, tooth mobility, suppuration, and periodontal abscess). This decision was made by the periodontal resident and approved by a faculty member when the tooth was given a hopeless prognosis.[28] If a tooth was extracted for any other reasons (decayed, fractured, endodontic, or prosthodontic reasons), this tooth was excluded from the analysis. However, teeth that were extracted as a result of combined tooth decay and periodontal disease were included. Additionally, the effect of the recorded variables on the treated teeth was assessed for their potential effect on tooth retention/survival.

2.4.2 | Clinical outcomes of APT

The changes in the clinical parameters (PD, CAL, REC) were compared from baseline to the 3- to 6-months re-evaluation appointment. Additionally, the influence of other recorded variables was assessed on the changes in clinical parameters.

2.4.3 | Effect of non-surgical and surgical mechanical debridement on the vertical and horizontal components of the furcation defects

The vertical furcation classification was determined from periapical radiographs that were collected at baseline and 1 year (12 ± 3 months) following the surgery according to Tonetti et al. 2017.[22] Briefly, the vertical component was calculated by one investigator (JM) and was based on the amount of bone loss in the furcation defect, Class A was designated when bone loss reached the coronal third (<33%) of the furcation region, Class B was when the bone loss reached the middle third (33%–67%) of the furcation region, and Class C was assigned when the bone loss reached the apical third >67%) of the furcation region.[29] The investigator (JM) performed the first 15 vertical furcation component measurements twice. The values obtained at baseline were then compared with the values obtained from radiographs taken at the 1-year follow-up. And based on the Cohen weighted kappa, the reliability assessment of the two columns was 0.901 (95% confidence interval (CI), 0.829 to 0.973). The horizontal classification of the furcation was based on assessment with the use of a Naber's probe* as extracted from clinical records.[2] Briefly, this was measured based on horizontal probe penetration in the furcation region of a multirooted tooth; Degree 1 was assigned when the horizontal loss of periodontal tissue support was <3 mm; Degree 2 was assigned when there was a horizontal loss of support that had ≥3 mm but not the total width of the furcation area; and Degree 3 was assigned when a horizontal through-and-through destruction of the periodontal tissue in the furcation area had been observed.[2] The values obtained at baseline were then compared with the values obtained at the 3- to 6-months post-surgical re-evaluation appointment.

2.5 | Data management and statistical analysis

Descriptive statistics were performed and reported as frequencies and percentages for categorical variables and as means (±) SD for continuous outcomes. The changes in clinical parameters—CAL, PD, and REC—from baseline to the 3- to 6-months re-evaluation appointment were assessed with dependent *t* tests.

Mixed-effects uni- and multi-level regression analyses were achieved to identify predictive factors for CAL, PD, and REC at the 3- to 6-months re-evaluation appointment. Kaplan–Meier survival probabilities were calculated, and

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the curves for the entire follow-up period were subsequently plotted.

Multivariate Cox Proportional Hazard models were used for assessing correlations between independent variables and tooth loss, accounting for the fact that an individual may have attributed to multiple treated furcation defects (shared frailty was accounted for by including random effects).

Stepwise regression analyses were performed using likelihood ratio tests. Hazard ratios (HR) and corresponding 95% CIs were generated. All analyses were performed by a separate investigator (AS) using SPSS (IBM, released 2019, SPSS Statistics for Windows Version 26.0, Armonk, New York). The plots were generated using Origin software (OriginPro, Version 2019b. OriginLab, Northampton, Massachusetts) and Rstudio (Version 1.1.383, RStudio, Boston, Massachusetts), the survminer,[30] survival,[31] and ggplot2[32] packages. The level of significance was set at P <0.05 for all statistical testing.

Cohen weighted kappa was performed to assess the reliability of the two sets of measurements performed for the vertical furcation involvement component.

3 | RESULTS

3.1 | Study population

A total of 158 patients (78 males and 80 females; mean age, 49 ± 13.79 years; 55 smokers; 22 with controlled type II diabetes) with 184 treated furcation defects were included in this study (see Supplementary Figure 1 in online *Journal of Periodontology*). Out of these furcation defects, 140 were treated only with non-surgical mechanical debridement (SRP), and 44 were treated with SRP followed by surgical mechanical debridement (28 with OFD alone, and 16 with OFD and odontoplasty). The mean follow-up for the selected cases was 7.52 ± 4.05 years. During the follow-up, the average SPT visits for the included patients were 3.07 ± 0.88 times per year. The characteristics of the subject sample at baseline are summarized in Supplementary Table S2 in online *Journal of Periodontology*.

3.2 | Survival analysis

From baseline until the final follow-up appointment (7.52 ± 4.05 years), 64 teeth in 62 patients were lost. The 5- and 10-year FI tooth survival rates were 88.3% and 61.3%, respectively. Figure 1 demonstrates the survival curves of the treated molars, and the life table analysis which present the number of followed, censored, and extracted teeth per

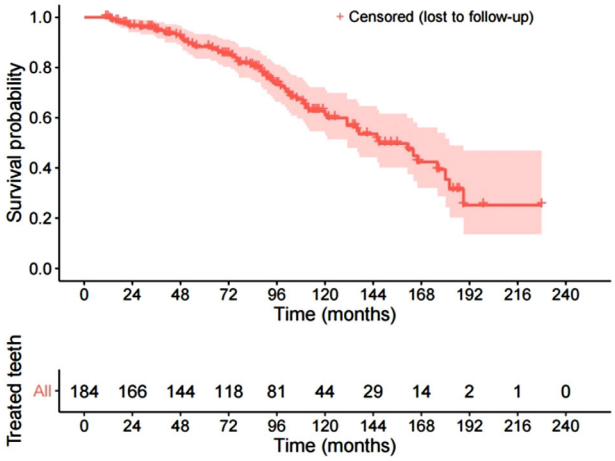

FIGURE 1 Kaplan–Meier survival curve for the entire follow-up period. Each event represents a tooth loss

year of follow-up (see Supplementary Table S3 in online *Journal of Periodontology*).

Results from the multivariate model of the multi-level Cox Proportional Hazard Models evaluating the influence of potential variables on FI tooth survival demonstrated that when compared with Degree 1 FI, Degree 2 FI (2.368 [95% CI, 1.151 to 4.874], P = 0.019), and Degree 3 FI (9.094 [95% CI, 2.998 to 27.585], P <0.001), negatively affected the survival of the treated molars. In addition, when the PD, CAL, and restorative treatment factors were excluded from the multivariate model, Class C FI had a higher chance of tooth loss when compared with Class A (2.907 [95% CI, 1.565 to 5.401], P = 0.001) (see Supplementary Table S4 in online *Journal of Periodontology*). However, the patients that attained more SPT had less risk for tooth loss (0.456 [95% CI, 0.319 to 0.653]; P <0.001). Visual representation comparing the survival curves of teeth with a different horizontal and vertical extent of FI are presented in Figure 2. The odds ratios (OR) and 95% CI of tooth loss are presented in Table 1. Comparison of the survival of upper versus lower molars based on the extent of their horizontal and vertical furcation involvement is shown in Supplementary Table S5 in online *Journal of Periodontology*.

3.3 | Clinical outcomes

At baseline, 45.16% of sites presented with BOP, a mean PD of 4.90 ± 1.16 mm, REC of 0.46 ± 0.59 mm, and CAL of 5.36 ± 1.02 mm. At the 3- to 6-months re-evaluation appointment, the BOP decreased to 23.11%, an average of 1.39 ± 0.99 mm PD reduction, and 0.88 ± 1.29 mm of CAL gain were observed. In addition, an increase of 0.51 ± 1.13 mm

TABLE 1 Results of the multi-level cox proportional hazard models evaluating the effect of different variables on the survival of the treated teeth

	Univariate analysis				Multivariate analysis			
Variable	**HR**	**SE**	**95% CI**	***P* value**	**HR**	**SE**	**95% CI**	***P* value**
Age	1.008	0.010	(0.988 to 1.028)	0.440				
Sex (male)	1.209	0.278	(0.701 to 2.084)	0.494				
Smoking	**1.898**	**0.275**	**(1.108 to 3.251)**	**0.020**	1.766	0.316	(0.951 to 3.281)	0.072
Diabetes	1.378	0.355	(0.688 to 2.762)	0.366				
Maintenance per year	**0.548**	**0.121**	**(0.432 to 0.695)**	**<0.001**	**0.456**	**0.183**	**(0.319 to 0.653)**	**<0.001**
Baseline PD	1.089	0.103	(0.890 to 1.333)	0.406				
Baseline CAL	1.014	0.124	(0.795 to 1.293)	0.914				
Re-evaluation PD	**1.289**	**0.096**	**(1.068 to 1.557)**	**0.008**	1.176	0.252	(0.717 to 1.928)	0.521
Re-evaluation CAL	**1.406**	**0.079**	**(1.205 to 1.641)**	**<0.001**	1.088	0.269	(0.642 to 1.844)	0.753
Endodontic treatment	0.288	0.720	(0.070 to 1.183)	0.084				
Restorative treatment	**0.242**	**0.518**	**(0.088 to 0.667)**	**0.006**	0.329	0.578	(0.106 to 1.022)	0.055
Furcation location – ref:Buccal lower								
Lingual lower	0.906	0.358	(0.449 to 1.828)	0.782				
Buccal upper	0.793	0.357	(0.394 to 1.596)	0.515				
Mesio-palatal	0.868	0.428	(0.375 to 2.008)	0.741				
Open flap debridement – ref: no								
Yes with or without and odontoplasty	0.890	0.281	(0.513 to 1.545)	0.680				
Vertical component[3] – ref: Class A								
Class B	1.217	0.297	(0.679 to 2.179)	0.510				
Class C	**2.802**	**0.317**	**(1.507 to 5.213)**	**0.001**	1.670	0.525	(0.597 to 4.669)	0.328
Horizontal component [2]– ref: Degree 1								
Degree 2	**2.619**	**0.302**	**(1.449 to 4.735)**	**0.001**	**2.368**	**0.368**	**(1.151 to 4.874)**	**0.019**
Degree 3	**10.898**	**0.378**	**(5.200 to 22.839)**	**<0.001**	**9.094**	**0.566**	**(2.998 to 27.585)**	**<0.001**

The values in bold signify statistical significance; CI, confidence intervals.

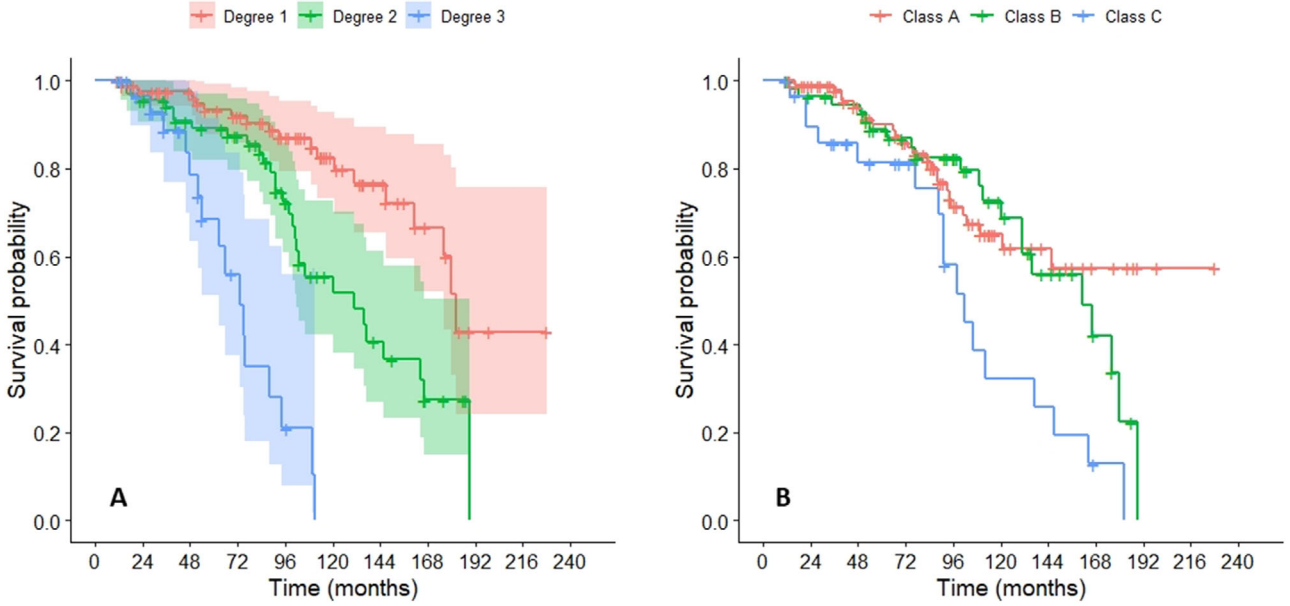

FIGURE 2 Kaplan–Meier survival curves displaying: **A**) the comparison between Degree 1, 2, and 3 horizontal extent of furcation involvement; **B**) the comparison between Class A, B, and C vertical extent of furcation involvement. Event = tooth loss

in REC was also noted. All the clinical parameter changes were statistically significant (P <0.001). When comparing teeth receiving SRP to teeth receiving OFD, a non-statistically significant CAL gain (0.89 ± 1.19 mm for SRP and 0.84 ± 1.57 mm for OFD, $P = 0.862$) and PD reduction (1.27 ± 0.87 mm for SRP and 1.75 ± 1.22 mm for OFD, $P = 0.019$) were observed. On the other hand, a statistically significant more pronounced REC was observed in the OFD group (0.39 ± 0.72 mm for SRP and 0.91 ± 0.94 mm for OFD, $P = 0.001$).

3.4 | Factors affecting the clinical outcomes

The results from the univariate and multivariate analysis on CAL, PD, and REC are presented in Table 2.

3.4.1 | Clinical attachment level changes (Table 2 [A])

A multivariate analysis evaluating the predictors of CAL gain found that the degree of horizontal and vertical furcation involvement highly influenced the levels of CAL gain. In fact, Degree 2 FI (-1.022 [95% CI, -1.327 to -0.716], P <0.001), Degree 3 FI (-1.787 [95% CI, -2.184 to -1.391], P <0.001) and Class C FI (-1.277 [95% CI, -1.654 to -0.899], P <0.001) were all associated with lower levels of CAL gain.

3.4.2 | PD changes (Table 2 [B])

When examining the potential factors affecting the levels of PD reduction, multivariate analysis revealed FI teeth with deeper initial PD (0.225 [95% CI, 0.042 to 0.408], P = 0.016) had significantly higher PD reduction. On the other hand, teeth with Class C (-0.665 [95% CI, -0.976 to -0.353], P <0.001), Degree 2 (-0.968 [95% CI, -1.210 to -0.727], P <0.001), and Degree 3 (-1.082 [95% CI, -1.389 to -0.774], P <0.001) had lower levels of PD reduction.

3.4.3 | Recession depth changes (Table 2 [C])

In assessing the effect of different variables on REC of the treated defects, patients that had open flap debridement had higher levels of recession (0.416 [95% CI, 0.146 to 0.686], P = 0.003). Teeth presenting with higher levels of PD (0.311 [95% CI, 0.157 to 0.465], P <0.001), Class C (0.803 [95% CI, 0.542 to 1.064], P <0.001) and Degree 3 (0.830 [95% CI, 0.591 to 1.069], P <0.001) FI were also associated with more REC at the 3- to 6-months re-evaluation appointment.

3.4.4 | Effect of furcation defect's horizontal and vertical components on the clinical outcomes

Results from the Kruskal–Wallis test showed that when dividing the treated furcation defects based on their

TABLE 2 Results of the regression models evaluating the effect of different variables on the CAL (A), REC (B), and PD (C) of the treated defects at the 3- to 6-month re-evaluation appointment

	Univariate analysis				Multivariate analysis			
Variable	**Estimate**	**SE**	**95% CI**	***P* value**	**Estimate**	**SE**	**95% CI**	***P* value**
(A)								
Age	-0.004	0.008	(-0.019 to 0.011)	0.579				
Sex (male)	-0.103	0.209	(-0.516 to 0.309)	0.622				
Smoking	-0.218	0.219	(-0.650 to 0.214)	0.320				
Diabetes	-0.545	0.299	(-1.135 to 0.044)	0.070				
Baseline PD	-0.002	0.085	(-0.170 to 0.166)	0.979				
Baseline CAL	0.051	0.097	(-0.140 to 0.242)	0.596				
Furcation location – ref: Buccal lower								
Lingual lower	0.023	0.280	(-0.531 to 0.576)	0.936				
Buccal upper	0.412	0.269	(-0.118 to 0.942)	0.127				
Disto-palatal	0.324	0.276	(-0.221 to 0.869)	0.242				
Mesio-palatal	-0.439	0.345	(-1.120 to 0.242)	0.205				
Open flap debridement – ref: No								
Yes	-0.386	0.264	(-0.907 to 0.136)	0.146				
Yes with odontoplasty	0.552	0.337	(-0.113 to 1.217)	0.103				
Vertical component [3] – ref: Class A								
Class B	-0.084	0.194	(-0.468 to 0.299)	0.664				

(Continues)

TABLE 2 (Continued)

Variable	Univariate analysis				Multivariate analysis			
	Estimate	SE	95% CI	*P* value	Estimate	SE	95% CI	*P* value
Class C	**-1.555**	**0.243**	**(-2.035 to -1.074)**	**<0.001**	**-1.277**	**0.191**	**(-1.654 to -0.899)**	**<0.001**
Horizontal component [2]– ref: Degree 1								
Degree 2	**-1.097**	**0.172**	**(-1.436 to -0.758)**	**<0.001**	**-1.022**	**0.155**	**(-1.327 to -0.716)**	**<0.001**
Degree 3	**-1.967**	**0.222**	**(-2.404 to -1.529)**	**<0.001**	**-1.787**	**0.201**	**(-2.184 to -1.391)**	**<0.001**
(B)								
Age	-0.002	0.006	(-0.014 to 0.010)	0.745				
Sex (male)	-0.243	0.161	(-0.561 to 0.076)	0.134				
Smoking	-0.083	0.170	(-0.419 to 0.253)	0.627				
Diabetes	-0.221	0.234	(-0.683 to 0.241)	0.345				
Baseline PD	**0.221**	**0.060**	**(0.101 to 0.340)**	**<0.001**	**0.225**	**0.093**	**(0.042 to 0.408)**	**0.016**
Baseline CAL	**0.223**	**0.069**	**(0.086 to 0.360)**	**0.002**	0.092	0.107	(-0.120 to 0.303)	0.394
Furcation location – ref: Buccal lower								
Lingual lower	-0.095	0.217	(-0.523 to 0.332)	0.661				
Buccal upper	0.119	0.207	(-0.290 to 0.528)	0.567				
Disto-palatal	-0.060	0.213	(-0.481 to 0.361)	0.778				
Mesio-palatal	-0.376	0.267	(-0.902 to 0.150)	0.160				
Open flap debridement – ref: No								

(Continues)

TABLE 2 (Continued)

Variable	Univariate analysis				Multivariate analysis			
	Estimate	SE	95% CI	*P* value	Estimate	SE	95% CI	*P* value
Yes	0.371	0.200	(-0.023 to 0.766)	0.065				
Yes with odontoplasty	**0.666**	**0.255**	**(0.163 to 1.169)**	**0.010**	0.187	0.193	(-0.193 to 0.567)	0.333
Vertical component [3]– ref: Class A								
Class B	-0.001	0.162	(-0.320 to 0.319)	0.997				
Class C	**-0.541**	**0.203**	**(-0.941 to -0.141)**	**0.008**	**-0.665**	**0.158**	**(-0.976 to -0.353)**	**<0.001**
Horizontal component [2]– ref: Degree 1								
Degree 2	**-1.018**	**0.138**	**(-1.291 to -0.745)**	**<0.001**	**-0.968**	**0.122**	**(-1.210 to -0.727)**	**<0.001**
Degree 3	**-0.994**	**0.178**	**(-1.346 to -0.642)**	**<0.001**	**-1.082**	**0.156**	**(-1.389 to -0.774)**	**<0.001**
(C)								
Age	0.002	0.005	(-0.007 to 0.011)	0.616				
Sex (male)	-0.139	0.125	(-0.387 to 0.108)	0.268				
Smoking	0.135	0.132	(-0.125 to 0.395)	0.306				
Diabetes	0.324	0.180	(-0.031 to 0.679)	0.073				
Baseline PD	**0.223**	**0.050**	**(0.123 to 0.322)**	**<0.001**	**0.311**	**0.078**	**(0.157 to 0.465)**	**<0.001**
Baseline CAL	**0.172**	**0.059**	**(0.055 to 0.288)**	**0.004**	0.017	0.052	(-0.086 to 0.119)	0.746
Furcation location – ref: Buccal lower								
Buccal upper	-0.293	0.167	(-0.622 to 0.037)	0.082				

(Continues)

TABLE 2 (Continued)

Variable	Univariate analysis				Multivariate analysis			
	Estimate	SE	95% CI	*P* value	Estimate	SE	95% CI	*P* value
Disto-palatal	**-0.384**	**0.172**	**(-0.723 to -0.045)**	**0.027**	-0.219	0.111	(-0.430 to 0.001)	0.051
Lingual lower	-0.118	0.174	(-0.462 to 0.226)	0.500				
Mesio-palatal	0.063	0.215	(-0.360 to 0.487)	0.768				
Open flap debridement – ref: No								
Yes	**0.757**	**0.157**	**(0.447 to 1.068)**	**<0.001**	**0.416**	**0.137**	**(0.146 to 0.686)**	**0.003**
Yes with odontoplasty	0.114	0.201	(-0.282 to 0.510)	0.570				
Vertical component [3]– ref: Class A								
Class B	0.084	0.120	(-0.153 to 0.321)	0.485				
Class C	**1.014**	**0.150**	**(0.718 to 1.310)**	**<0.001**	**0.803**	**0.132**	**(0.542 to 1.064)**	**<0.001**
Horizontal component [2]– ref: Degree 1								
Degree 2	0.079	0.118	(-0.153 to 0.312)	0.502				
Degree 3	**0.973**	**0.152**	**(0.673 to 1.273)**	**<0.001**	**0.830**	**0.121**	**(0.591 to 1.069)**	**<0.001**

The values in bold signify statistical significance; CI, confidence intervals.

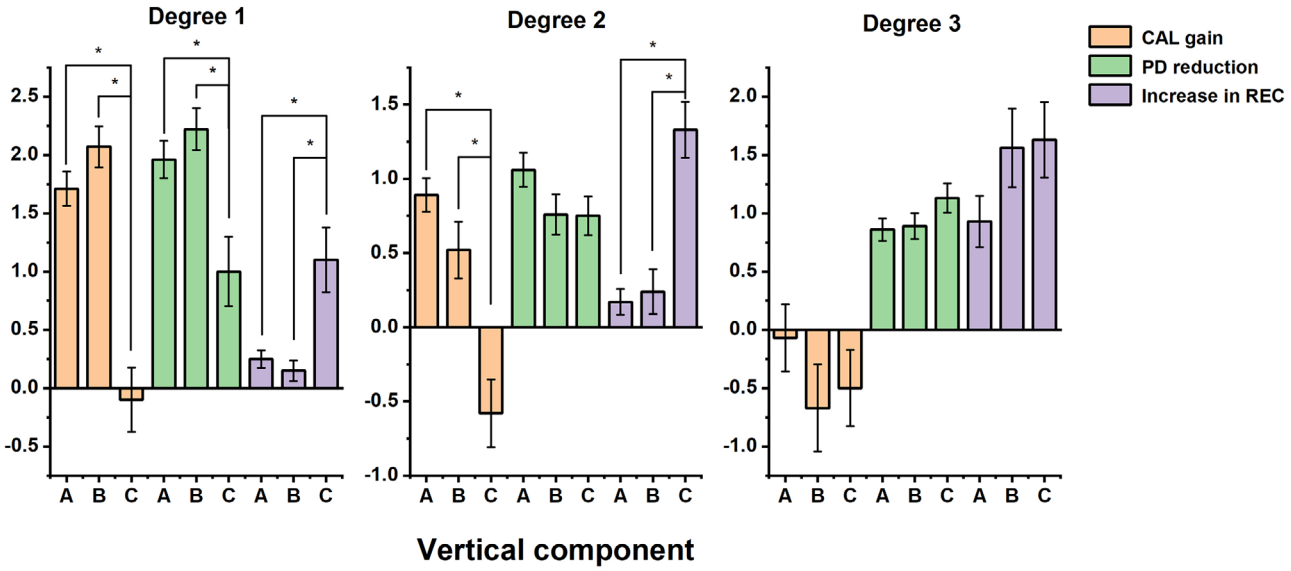

FIGURE 3 Horizontal (Degree 1, 2, and 3) and vertical (Class A, B, and C) component dependent clinical measure changes at the 3- to 6-month re-evaluation appointment. *The difference from the values obtained with vertical furcation component C is statistically significant

merged extent of horizontal and vertical involvement, molars with minimal horizontal involvement (Degree 1) and lower vertical involvement (Class A and B) had the most CAL gain with minimal REC. In general, molars with Degree 2 FI did not witness major changes in CAL. It was clear, however, that FI teeth that presented with extensive periodontal tissue loss horizontally and vertically (Degree 3 and Class C, respectfully) had lower levels of CAL gain, mainly as a consequence of high levels of REC (Fig. 3).

In terms of change in the horizontal and vertical extent of FI, out of 82 teeth presenting initially with a Degree 1 FI, 75 remained Degree 1, six became Degree 2, and one case turned out to be Degree 3 at the 3- to 6-months re-evaluation appointment. Most of the teeth that were diagnosed with Degree 2 (58 out of 68) remained the same; four improved to Degree 1 and six defects converted to Degree 3. Finally, all the teeth that presented with Degree 3 FI remained with the same horizontal extent of FI.

Results from the Cohen weighted kappa showed that the reliability assessment of the two sets of vertical furcation involvement component measurements was 0.901 (95 CI, 0.829 to 0.973). When the change in the vertical component of FI was evaluated, we found that out of 97 teeth presenting with Class A FI, 85 teeth maintained the same status, 11 worsened to Class B, and one tooth was diagnosed with Class C 1 year following APT intervention. Class B FI teeth mostly remained the same (52 out of 57 teeth) and worsened to become Class C in five FI teeth. All teeth presenting with a Class C FI remained mostly unchanged after 1 year (Fig. 3).

4 | DISCUSSION

The present investigation assessed patients with furcation involved molars undergoing APT (SRP or OFD) for an average of 7 years.

This study focused on the clinical parameter changes and the factors affecting the success of APT. We believe that knowing these factors are of great clinical interests. Despite that the clinical parameters recorded before and after APT, both did not seem to influence tooth survival in our multivariate analysis, it seemed in the univariate analysis that CAL and PD obtained following APT (at the 3- to 6-months re-evaluation appointment) had a significant influence on tooth survival, in contrast to baseline CAL and PD that did not significantly affect tooth survival. This signifies that a successful APT leading to CAL gain and PD reduction might actually prolong the dentition lifespan, and highlights the importance of efficacious APT. Our results found that a statistically significant CAL gain of 0.88 ± 1.29 mm, PD reduction of 1.39 ± 0.99 mm, and REC increase of 0.51 ± 1.13 mm occurred at the 3- to 6-months re-evaluation appointment. This finding is in line with other studies evaluating the effect of surgical and non-surgical mechanical root debridement. In fact, Graziani and colleagues, in a systematic review and meta-analysis assessing randomized clinical trials that evaluated the effect of OFD on Degree 2 FI found 0.55 mm CAL gain, 1.38 mm PD reduction, and a 0.73 mm increase in REC 6 months following the treatment.[33] Similarly, Dannewitz and colleagues assessed the effect of non-surgical instrumentation of furcation sites with and without doxycycline and

reported a CAL gain of 0.85 mm and a PD reduction of 0.9 mm 6 months following SRP in their control group.[34] In fact, FI molars have shown to respond less favorably to SRP compared with non FI molars.[35,36] Interestingly, these changes are comparable with those obtained with GTR of FI teeth.[12,13,37]

When analyzing the effect of mucoperiosteal flap reflection (SRP versus OFD), we found that flap refection did not significantly affect PD reduction or CAL gain but only increased the chance of gingival recession. This might be due to tissue injury resulting from the surgical separation of the sulcular/pocket epithelium and gingival connective tissue fibers from the tooth.[38,39] Finally, molars that presented with higher levels of initial PD had more PD reduction at the re-evaluation appointment. This finding might mainly be due to a higher level of gingival recession experienced in these cases.

FI has been widely established as a risk factor for tooth loss.[24,25,40–42] In fact, FI is one of the most important factors determining the periodontal prognosis of molar teeth.[43] Therefore, the primary outcome of the present study was the survival of the treated furcation-involved molars. Results from the present study observed survival rates of 88.3% and 61.3% for molars treated with non-surgical/surgical mechanical debridement at 5 and 10 years, respectively. In a previous report we conducted on the effect of GTR on FI teeth, we observed survival rates of 86.5% and 74.3% for the GTR treated molars at 5 and 10 years, respectively.[13] In this sense, it seems that GTR does not affect the short-term survival of FI teeth but increases the long-term survival of the treated teeth when compared with mechanical root debridement. In the current study, tooth survival was highly impacted by the average SPT appointment during study period. In fact, teeth that were extracted had received less SPT visits (2.55 ± 0.85 appointments/year for the lost teeth versus 3.33 ± 0.77 for the teeth that were maintained in the oral cavity).

Perhaps another factor that influences molar tooth survival clinical outcomes, was the furcation defect morphology. Furcation defects with a Class C vertical component or Degree 2 and 3 horizontal components experienced less CAL gain and PD reduction at the 3- to 6-months re-evaluation appointment (Table 2 [A] and [C]). In addition, furcation defects with a severe horizontal and vertical extent of periodontal destruction (Degree 3 and Class C) had significantly more REC when compared with shallower defects (Table 2 [B]). When the clinical outcomes were assessed based on the combined horizontal and vertical extent of furcation involvement, we observed that Type 1-A and 1-B FI were the defects responded the most favorably to APT (CAL gain average: 1.7 to 2 mm). Our results are in line with the literature; in fact, according to the reports by the American Academy of Periodontology Regeneration Workshop,[44,45] Degree 1 furcation defects are usually successfully treated with non-regenerative therapy. Nonetheless, we recommend diagnosing FI based on their horizontal as well as vertical extent of periodontal tissue destruction. Type 2A and 2B FI seem to respond less to APT. Histological proof of periodontal regeneration were most observed in teeth with Degree 2 FI, especially with GTR.[45–48] This could be attributed to the containment of the space in Degree 2 FI defects, where >3 mm of horizontal space is available to contain bone graft that is packed against a bony wall and could then be covered with a membrane to provide a high level of stability.[15] Our data also showed that Degree 3 FI responded poorly to the treatment; root resection and tunneling procedures have been recommended in treating these defects when patients' oral hygiene and tooth anatomy are favorable.[9,14,49] Finally, the treatment also failed to benefit furcation defects with a deep vertical bony component (Class C). Other treatment options such as extraction, alveolar ridge preservation, and implant placement might be considered for these defects. These findings emphasize the value of understanding the three-dimensional anatomy of the furcation defect to establish the correct treatment option for managing this condition.

Moreover, when the survival of the treated FI teeth was compared based on their horizontal or vertical extent of involvement, the Kaplan–Meier analysis clearly showed the positive association between tooth loss and the horizontal degree of involvement (Fig. 2A). When assessing the FI teeth based on their vertical component, we observed that teeth with Class C FI had a higher chance of tooth loss when compared with Class A and B (which had similar survival rates up to 11 years). However, Class A had significantly higher survival rates when compared with Class B in the longer term (Fig. 2B). Identifying a strong relationship between the extent of horizontal/vertical furcation involvement and the risk of tooth loss from this study is in agreement with a recent study.[23] In this study, the authors examined 633 FI molars undergoing SPT regularly and reported that FI molars with severe horizontal and vertical components had poor long-term tooth survival rate.[23] Thus, the horizontal and vertical defect components are critical aspects when assigning a prognosis to molar teeth with FI.

Among the limitations of this study are the retrospective nature of this project, and the absence of a standardized protocol for the radiographic assessment, which would have increased the reliability and precision of our measurements. It has been shown that there is a tendency to under- or over-estimate the amount of bone loss when evaluating two-dimensional radiographs.[50] In addition, when assessing the radiographic vertical component of maxillary molar furcation defects, the presence of a third

palatal root could potentially lead to a less reliable diagnosis when compared with mandibular furcation defects.[23] The unequal and relatively reduced sample size of the defects, particularly in some of the subclassifications, may limit the ability to generalize our results. Furthermore, it may be possible that due to the true clinical nature some defects, molas with a combined defect may have been under looked. Additionally, the notion that all patients had been from the same patient pool of a university setting and had received varieties of SPT regimen (some sporadic and minimal as low as one SPT/year), may limit the generalizability of our findings and its external validity, therefore we deem necessary future investigations to corroborate our results.

5 | CONCLUSIONS

Our study is not free of limitations as mentioned above. However, it can be concluded that non-surgical and surgical mechanical root debridement were viable treatments for managing teeth with shallow furcation defects, particularly for teeth with Degree 1 and Class A/B furcation defects. Factors such as supportive periodontal therapy frequency, as well as the horizontal and vertical extent of involvement significantly affected the survival of FI teeth undergoing maintenance therapy.

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AUTHOR CONTRIBUTIONS

Dr. Majzoub, Dr. Tavelli, Dr. Barootchi, Dr. Wang, and Dr. Chan contributed to the conception and design of the work. Dr. Majzoub, Dr. Tavelli, and Dr. Barootchi collected the data; Dr. Salami analyzed the data; Dr. Majzoub and Dr. Salami designed the schematic illustrations; and Dr. Majzoub, Dr. Wang, and Dr. Chan led the writing.

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SUPPORTING INFORMATION

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