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ORIGINAL ARTICLE

Effect of different instrumentation techniques on students' performance and outcomes of nonsurgical root canal treatment

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Abstract

Objectives: This study compared, retrospectively, the incidence of clinical errors and effects on treatment outcomes, when students were exposed to two different instrumentation techniques: a hybrid rotary technique (HYB), consisting of both hand instrumentation with hand stainless steel and Ni-Ti files plus the use of a rotary system (Vortex Blue, Dentsply Sirona), versus a full reciprocation instrumentation technique (WaveOne Gold [WOG], Dentsply Sirona).

Methods: A total of 368 endodontic cases ($n = 184$) in anterior and premolar teeth, completed by dental students at the University of Michigan School of Dentistry from 2013 to 2022, were used for the study. The groups were evaluated by two calibrated clinicians, observing the incidence of clinical errors: file separations, over-instrumentation, ledges and transportations. Treatment outcomes were also observed. Data were analyzed statistically by Fisher's exact test and Mann–Whitney U test ($p < 0.05$).

Results: No significant difference in file separations, ledges, and transportation was observed between the two groups. However, the WOG Group experienced significantly more over-instrumentation than HYB group, although this did not significantly affect tooth survival or periapical index (PAI). Cases with PAI scores of 5 were found to have significantly less tooth survival compared to the other PAI scores.

Conclusions: It can be concluded that both techniques in our study are well suited to advancing the endodontic dental education of students and novice operators, anticipating relatively successful outcomes of tooth survival, as long as the cases selected are less severe in progression preoperatively.

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KEYWORDS
endodontics, Ni-Ti, predoctoral education

1 | INTRODUCTION

The use of Ni-Ti rotary instruments by inexperienced operators has brought new insights on the safety of these regarding the incidence of operative errors. The development of reciprocation systems has shown a greater ability, as these instruments work by a 150° counterclockwise motion where it engages, cuts dentin and advances in the canal and a 30° clockwise where it disengages for safe progression through the canal and to reduce the risk of fractures by the "screw-in" tendency.[1,2] In addition to the motion, WaveOne Gold [WOG] incorporates the benefits of heat treatment ("Gold") that has been reported to provide enhanced flexibility, resistance to cyclic fatigue, cutting sharpness, and efficiency.[2–4] This instrument has a unique design with an offset parallelogram shape. This design allows for only one or two points of contact between the cutting edges and the canal wall, resulting in better efficiency and increased resistance to fractures.[5,6]

This increased efficiency and resistance to fractures can be considered one of the main reasons for adoption of reciprocation instruments for early learners. The literature shows that reciprocal motion instrumentation reduces procedural errors, including the incidence of ledging,[7] file fracture,[8–11] and alteration of the original canal anatomy.[12,13] It also has a lower incidence of procedural errors than manual instrumentation or Ni-Ti rotary instrumentation.[14–16] These advantages were also observed by a limited number of studies, which also focused on the use of these instruments by novice practitioners, as the advantages in reducing preparation errors in contrast to manual instrumentation were emphasized.[15] For inexperienced operators, torsional stresses with conventional rotary Ni-Ti files can be a challenge,[15] and reciprocal motion is able to reduce these stresses.[17] Several studies[18–20] have shown that the use of reciprocating motion can also extend the life span of a Ni-Ti instrument and thus may increase clinical safety compared with continuous rotation. Rotary instrument separation occurs mainly through two mechanisms: torsional failure and cyclic fatigue.[21,22] Torsional overload corresponds to a static failure and happens when a section of the file is locked within the canal, and the shank continues to rotate. Cyclic fatigue occurs when a file rotates inside a curved root canal and experiences alternating compressive and tensile stresses and strains. This can cause sudden file fractures after a certain number of rotations.[23–25] Thus, the number of cycles until failure is cumulative and can be obtained through the multiplication of the rotational speed by the time elapse until fracture through cyclic fatigue occurs.[23] Interestingly, some studies[11,26] have found that the operator experience did not significantly influence the occurrence of defects with reciprocation instruments in order that they became an excellent option for dental students.

Although some studies looked into clinical errors with reciprocation versus rotary, not a lot has been observed regarding the outcomes of these treatments in the long term. Understanding and researching on instrument/technique performance is important for future developments of endodontic treatment protocols for dental students. Thus, this article aims to evaluate retrospectively if there is any difference in procedural errors and outcomes in cases done by dental students when using two different techniques: a hybrid rotary technique (HYB), consisting of both hand instrumentation with stainless steel files and use of a rotary system (Vortex Blue), versus a full reciprocation instrumentation technique (WOG). Treatment outcomes were also observed, as well as what factors influence the success rates of these treatments done by dental students. The null hypotheses are that the variation of techniques does not change the incidence of procedural errors, and that the different techniques would not affect the clinical outcomes.

2 | METHODOLOGY

2.1 | Case selection

This study was exempted from IRB review, as per submission and processing (protocol # HUM00212068). Data were collected from the dental school's computerized records (between 2013 and 2022). The following inclusion criteria were established: patients who received root canal treatment at the dental school (initial treatment) by predoctoral students and had complete medical and dental records. The exclusion criteria were as follows: teeth were excluded if radiographic interpretation was not possible during any of the following steps: initial diagnosis, working length (WL) determination, master apical file verification, gutta-percha point fit, or final obturation. No patient or student information was retrieved from the system, and no patient/student identifiers were used for the study. Pulpal diagnoses were divided into vital and nonvital cases. To carry out the power analysis, we assumed an

error rate of 25% in the WOG group[7] and 13.1% in the HYB group. We obtained a sample size of 184 cases in each group (a total of 368, group size ratio of 1) to have 80% power based on Fisher's exact test, assuming two-sided tests and a significance level of 0.05.

2.2 | Clinical protocol

All cases and procedures used for this study were supervised and signed off by Endodontics faculty. The cases were collected in two separate time spans: 2013–2018, when the technique used was hybrid (HYB); 2018–2022, when the adopted technique was the WOG.

Before instrumentation, all cases had the endodontic access completed and canal patency achieved with #10 K-file to the estimated WL. The WL was determined with apex locator and confirmed with a digital radiograph. Glide path was achieved using K-files #10, 15, and 20. Vortex 25/0.08 rotary orifice opener was used to instrument the coronal third of the canal. After these common procedures, cases were treated with one of the following techniques (HYB or WOG). Note that 4.125% sodium hypochlorite (NaOCl) was used as irrigation throughout the treatments.

2.3 | Hybrid instrumentation group

Crown-down instrumentation was done with Vortex (.04 taper) rotary files #45, 40, and 35 up to the middle third of the canal. Instrumentation up to WL was done using Profile Ni-Ti 0.04 hand files, starting with the file that binds at WL and up extra two sizes (e.g., 25, 30, 35, or 40). A master apical file (MAF) radiograph was taken with the last file used to instrument the canal.

2.4 | WOG instrumentation group

Instrumentation up to WL was done using the WOG reciprocation system. This was done up to the appropriate size according to the size of the canal (e.g. 25, 35 or 45). The canal size was determined in the following way: if the 25/0.07 file does not bind at length with no dentinal debris in the apical flutes, continue shaping with medium file (035/0.06) and/or large file (45/0.05) until the apical flutes are loaded, as per manufacturer's recommendations. MAF radiograph was taken with the last file used to instrument the canal.

After the instrumentation accordingly to the above described protocols, all canals received the same final irrigation protocol with 6.0 mL of 4.125% NaOCl, then 3.0 mL of 17% EDTA and 6.0 mL of 4.125% NaOCl. Canals were dried with paper points and a gutta-percha cone fit radiograph was taken. The obturation was done with gutta-percha and AH Plus sealer using cold lateral condensation technique. Following treatment, patients were scheduled for post-treatment evaluation (PTE), where signs, symptoms, or postoperative complications were recorded, with the type of restoration placed and radiographic interpretation.

2.5 | Data collection

For the present study, the clinical outcomes were obtained by interpreting the treatment and follow-up radiographs. Results were classified as follows[27,28]:

1. Healed/healing (favorable outcome):
2. Healed (complete healing): absence of a periapical lesion with no pain, swelling or discomfort.
3. Healing (incomplete healing): reduction in the periapical lesion size but not completely resolved with no pain, swelling, or discomfort.
4. Not healing (unfavorable outcome):
5. It includes no change in the size of the periapical lesion/increase in the size of the periapical lesion/development of a new periapical lesion.
6. It includes development of clinical signs or symptoms (pain, swelling or discomfort).

Besides the clinical outcomes, multiple host, treatment, and procedural errors variables were recorded from the patients' records after a retrospective chart review.

Host factors are as follows:

1. Patient age (at the time of treatment).
2. Tooth type (anterior/ premolar).
3. Arch (maxillary/mandibular).
4. Pulp condition (vital/necrotic).
5. Periapical lesion: (present/absent).
6. Periapical lesion based on the periapical index (PAI)[29]:
   I. PAI 1: Normal periapical structures.
   II. PAI 2: Small changes in bone structure.
   III. PAI 3: Changes in bone structure with some mineral bone loss.
   IV. PAI 4: Periodontitis with well-defined radiolucent area.
   V. PAI 5: Severe periodontitis and exacerbating features.

Treatment factors are as follows:

1. MAF following instrumentation of each root canal system.

2. Density of the obturation is as follows:
3. Good: homogeneous radiopaque material with no visible space between the material and the walls of the canal and with no more than two small voids (<1 mm) along the entire obturation.
4. Poor: nonuniform radio-density, with multiple voids along the obturation and/or canal space visible laterally and apically.

Procedural errors (present or absent) are as follows:

1. Separated instrument(s)/files: These are Identified through observation of the radiograph and according to the radiopacity between the filling material and the fractured instrument.[30]
2. Canal transportation: It is identified when the extrusion of filling material was detected in any other area of the root, except the furcation area.[31,32]
3. Ledging: It is identified when the root obturation/MAF was at least 1 mm shorter than the initial WL, or deviated from the original curvature canal shape[31,32] or/and by treatment notes.
4. Over instrumentation: It can be identified when the MAF was seen beyond the radiographic apex.

2.6 | Calibration

Both intra- and inter-examiner calibration was conducted initially (pre-analysis) to determine the level of agreement and make adjustments. Calibrations were conducted using the Kappa test ($p < 0.05$) for obturation quality (inter: 0.8165; intra: 0.9082), PAI (inter: 0.9636; intra: 0.9696), and presence of periapical lesion (inter: 1.000; intra: 1.000), indicating strong level of agreement.

2.7 | Statistical analysis

Categorical variables are expressed as count and percentages and continuous variables as median and interquartile range (IQR). Comparative analyses for categorical variables were performed using Fisher's exact test and for continuous variables using Mann–Whitney *U* test. Two-tailed *p* values of <0.05 were considered significant. We performed a multivariable logistic regression, with instrumentation technique (WOB or HYB), MAF, and tooth number included as the covariates (independent variables), to compute their effects on procedural errors (dependent variable). Kaplan–Meier survival analysis with log-rank test was used to compare tooth survival (presence or absence of the tooth in the oral cavity) between the instrumentation groups, with the time-to-event function (defining "event" as the tooth extraction). We also used a bivariate cox proportional hazards regression model to compute hazard ratios and 95% confidence intervals of the effects of instrumentation technique and PAI on tooth survival (with the time to event function, defining "event" as the tooth extraction). All statistical analyses were performed using SPSS v.29.0.1.1 (IBM).

3 | RESULTS

In the HYB group, the median age of the patients was 59 years (interquartile range [IQR] 43–69 years) and 15 were current smokers (out of those patients whose smoking history was known). This was comparable to the patients in the WOG group whose median age was 55 years (IQR 41–69 years, $p = 0.316$) and 19 were known current smokers. Both groups comprised 97 (52.7%) anterior teeth and 87 (47.3%) premolars, with no significant differences in the distribution of tooth numbers between the two groups ($p = 0.550$). Tooth vitality was similar with 131 (71.2%) non-vital teeth in the HYB group and 141 (76.6%) non-vital teeth in the WOG group ($p = 0.285$). Periapical indexes were also similar across the two groups ($p = 0.992$). There was a significant difference in the MAF size, with 12 (6.5%) MAF < 35 in the HYB group compared to 63 (34.2%) MAF < 35 in the WOG group ($p < 0.001$). Data from this section are summarized in Table 1.

3.1 | Procedural errors

The total of procedural errors in the HYB group was 23 (12.5%) and in the WOG group was 45 (24.4%). There was a significant difference in the proportion of procedural errors between the groups with a *p*-value lower than 0.05 (Table 2). In the HYB group, 18 cases (9.8%) had over-instrumentation errors, three (1.6%) had canal transportation, two (1.1%) had ledges, and none had instrument separation. In the WOG group, 45 (24.5%) had over-instrumentation errors, but there were no canal transportation, ledge, or instrument separation errors. The two groups had a significant difference in terms of over-instrumentation errors with a *p*-value of <0.001.

In the multivariable logistic regression analysis, WOG was associated with a higher odds of procedural errors compared to the HYB group (odds ratio [OR] of 2.414, 95% confidence interval [CI] 1.342–4.342, $p = 0.003$), while MAF ≥ 35 (OR 1.194, 95% CI 0.594–2.4, $p = 0.618$) and tooth number did not have a significant association with procedural errors (Table 3).

TABLE 1 Baseline characteristics of the study groups.

Baseline characteristics	HYB	WOG	*p*-Value*
Age in years [median, (IQR)]	59 (43, 69)	55 (41, 69)	0.316
Tooth type			
Anterior	97 (52.7%)	97 (52.7%)	1.000
Premolar	87 (47.3%)	87 (47.3%)	
Tooth vitality			
Vital	53 (28.8%)	43 (23.4%)	0.285
Non-vital	131 (71.2%)	141 (76.6%)	
Periapical index (PAI)			
Score 1	40 (21.7%)	42 (22.8%)	0.992
Score 2	45 (24.5%)	46 (25.0%)	
Score 3	56 (30.4%)	57 (30.8%)	
Score 4	34 (18.5%)	31 (16.8%)	
Score 5	9 (4.9%)	8 (4.3%)	
Master apical file (MAF)			
<35	12 (6.5%)	63 (34.2%)	**<0.001**
≥35	172 (93.5%)	121 (65.8%)	

Note: Bold values only highlighted the presence of statistical significance.
Abbreviations: HYB, hybrid rotary technique; IQR, interquartile range; WOG, WaveOne Gold.
*p-Values are two-sided and based on Fisher's exact test for categorical values and Mann–Whitney U test for continuous variables; $p < 0.05$ was considered statistically significant.

TABLE 2 Outcomes of tooth instrumentation with hybrid rotary technique (HYB) and WaveOne Gold (WOG).

Outcomes	HYB	WOG	*p*-Value*
Procedural errors[a]	23 (12.5%)	45 (24.5%)	**<0.005**
Over-instrumentation	18 (9.8%)	45 (24.5%)	**<0.001**
Canal transportation	3 (1.6%)	0 (0.0%)	0.248
Tooth survival[b]			
Teeth that survived	34 (18.5%)	10 (5.4%)	
Teeth that did not survive	143 (77.7%)	138 (75.0%)	**<0.001**
Unknown	7 (3.8%)	36 (19.6%)	

Note: Bold values only highlighted the presence of statistical significance.
[a]Crown perforations and missed canals were excluded as they may occur independently irrespective of instrumentation technique.
[b]Tooth survival data were unknown for seven cases in the hybrid group and 36 cases in the WaveOne Gold group. Follow-up time was variable.
*p-Values are two-sided and based on Fisher's exact test; $p < 0.05$ was considered statistically significant.Bold values only highlighted the presence of statistical significance

TABLE 3 Logistic regression: Factors affecting the prevalence of procedural errors.

Variable	Odds ratio (95% CI)	*p*-Value*
Instrumentation technique		
Hybrid	Control	**0.003**
WaveOne Gold	2.414 (1.342–4.342)	
MAF ≥ 35	1.194 (0.594–2.4)	0.618
Tooth group		
Maxillary anteriors and mandibular canines	Control	
Maxillary premolars	0.666 (0.325–1.364)	0.266
Mandibular premolars	0.916 (0.460–1.823)	0.802
Mandibular incisors	1.334 (0.483–3.689)	0.578

Note: Bold value indicates statistical significance.
Abbreviation: CI, confidence interval; MAF, master apical file.
*p-Values are two-sided; $p < 0.05$ was considered statistically significant.

3.2 | Survival analysis

The number of teeth that did not survive in the HYB group was 28 of 170 (16.47%). The number of teeth that did not survive in the WOG group was 10 of 148 (6.76%). Although the difference in the survival proportion was significant using Fisher's exact test ($p = 0.009$), when adjusted for follow-up time on the survival analysis, there was no statistically significant difference in tooth survival between the groups. The follow-up of the teeth in the HYB group ranged from 6 months to 9 years (median follow-up of 5 years, IQR 3–7 years), while the follow-up in the WOG group ranged from 3 months to 5 years (median follow-up of 2 years (IQR 1–3 years). A total of 170 cases in the HYB group and 148 cases in the WOG group had survival/follow-up times and were included in the survival analyses. The rest were excluded from the survival analyses. The Kaplan–Meier survival analysis showed no significant difference in tooth survival between the two instrumentation groups (log-rank test $p = 0.306$) (Figure 1). On the Cox proportional hazards regression model, we adjusted for the effect of PAI on tooth survival. Once again, the instrumentation technique had no significant effect on tooth survival (hazard ratio [HR] 0.719, 95% CI 0.339–1.525, $p = 0.390$). However, the effect of PAI of 5 was statistically significant, and teeth with PAI of 5 were more likely to not survive compared to teeth with PAI of 1 (HR 6.719, 95% CI 2.027–22.272, $p = 0.002$) (Figure 2).

4 | DISCUSSION

In this study, we sought to evaluate retrospectively the difference in procedural errors and outcomes between cases performed by dental students using a hybrid technique or the WOG reciprocating instrumentation systems.

We observed that over-instrumentation error was the most commonly reported type of error. This has

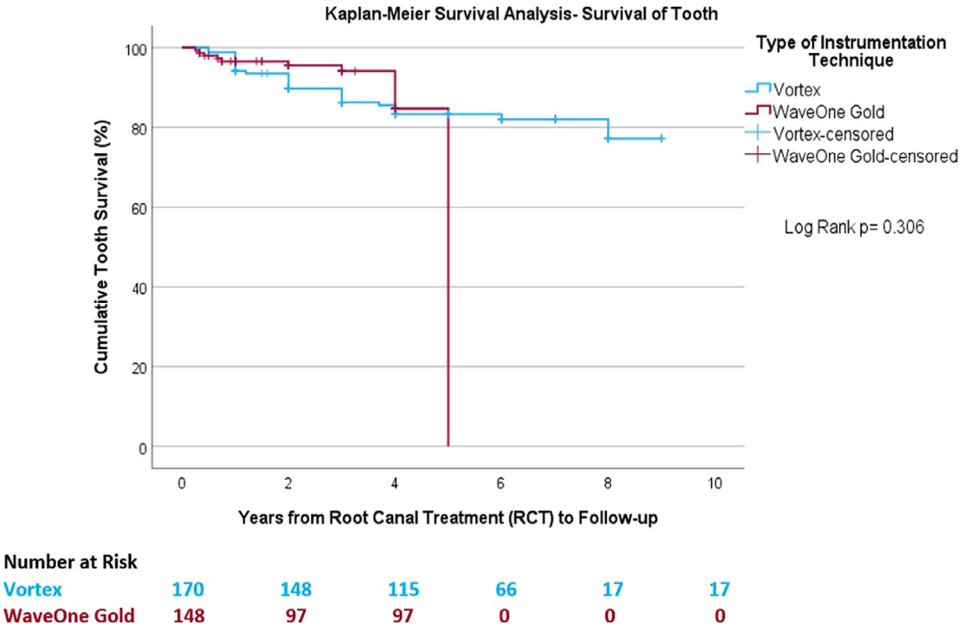
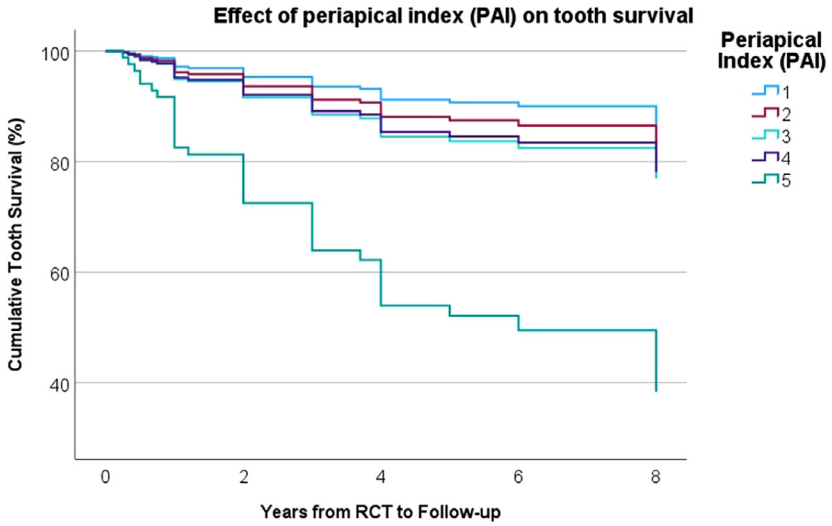


FIGURE 1 Kaplan–Meier curves showing tooth survival stratified by instrumentation technique.

FIGURE 2 Effect of periapical index (PAI) on tooth survival.



been reported to be a common mishap when using the reciprocating WOG file system.[33,34] In this study, 12 out of all the WOG cases were taken up to a 45/0.05, which might contribute to higher reports of over-instrumentation. Another possible explanation might be that the apical third of the HYB group was instrumented using Ni-Ti 0.04 hand files, whereas the apical third of the WOG group was instrumented with the reciprocation, which in novice hands might cause loss of apical control. This could be considered a problem regarding the clinical outcomes, as previous articles have shown apical changes[35] and a decrease in prognosis following over-instrumentation.[36] However, our results showed that over-instrumentation did not affect the outcomes in this particular sample size and population.

Regarding instrument separation, multiple studies using endodontic residents show a separation rate of 1.68%[37]–1.33[38]% with rotary instruments and a reduction (0.84%) with reciprocating files,[10] which is further reduced when the treatment was performed by an endodontist (0.13%).[9] This shows how reciprocation and the experience of the provider can reduce the instrument separation rate. Our study did not find any instances of instrument separation with either instrumentation technique. This could be due to our smaller sample size compared to previous studies,[9,10,37,38] and the fact that endodontic residents and

endodontists tend to handle more challenging cases with complex anatomies. In contrast, our study involved dental students who handled simpler cases. Nevertheless, having no separation rate in our study proves that both techniques in our study are very safe.

We also evaluated the effect of instrumentation and other factors on tooth survival instead of success, where we adopted a modified Friedman criterion.[27,28] In our study, the follow-up period for the teeth in HYB group was longer since their data were collected since 2013. Our median follow-up time in the HYB group was 5 years (IQR 3–7 years), while the median follow-up time in the WOG group was 2 years (IQR 1–3 years). Upon survival analysis, taking into account the time-to-event function, there was no statistically significant difference between the groups in terms of tooth survival. This result was in accordance with a systematic review of longitudinal clinical studies,[39] where they showed that there was no statistically significant difference in outcomes across studies in terms of the method of instrumentation.

On the other hand, when adjusting for PAI, teeth with PAI of 5 were associated with lower survival. This is in accordance with studies that show that large preoperative lesions negatively affect the outcomes of RCTs.[39–41] Higher levels of bacteria and endotoxins are found in teeth with larger sizes of radiolucent areas.[42–44] A higher number of bacteria is correlated with organized biofilms where bacteria adhere to the root canal walls and accumulate to form communities,[45] which can be important for bacterial resistance during and after intracanal antimicrobial procedures[46] and reflects the organization of the biofilm in apical segments.[47] In the WOG group, 10 (5.4%) teeth did not survive. The majority of teeth that did not survive were due to fractures, and the ones that did not survive because of persistent bacteria were the two teeth that remained symptomatic and a tooth where the palatal canal was missed. One hundred and thirty-eight (75.0%) teeth survived in the WOG group and 36 (19.6%) teeth did not have a PTE. The lack of PTE could be attributed to shorter time from the date of treatment to chart abstraction, compared to the HYB group, and also due to fewer PTE appointments in clinic during the COVID-19 pandemic. In comparison, the HYB group had 34 (18.5%) teeth that did not survive. The majority of these teeth fractured or were extracted for reasons not related to endodontic failure. Six teeth did not survive due to endodontic reasons. One hundred and forty-three (77.7%) teeth survived and only seven (3.8%) teeth did not have a PTE.

Comparing proportions of teeth that did not survive between the two groups is misleading because the HYB group had a significantly longer PTE time, and status of 19.6% teeth in the WOG group was unknown (compared to 3.8% in the HYB group). Hence, a survival analysis, which takes into account the time-to-event function as well as loss to follow-up, was deemed to be a more appropriate statistical method. A Kaplan–Meier survival analysis showed no statistical significance between the two instrumentation groups in terms of tooth survival. Furthermore, our study also found no significant association between tooth survival and patient age, tooth type, tooth number, tooth vitality, or MAF. Our study groups also had a very similar profile in terms of patient age, tooth type, tooth number, tooth vitality, and PAI, which further removes any potential effects of these factors on tooth survival. Multiple studies have shown a tooth survival rate of 88%–97% after root canal treatment,[48–50] which is similar to the overall tooth survival in our study (86%) upon excluding the teeth that did not have PTE. It is also important to emphasize that tooth survival after the endodontic treatment is directly related to the timely and adequate placement of a final restoration. Studies have shown that failure rates increase if the restorative treatment is not adequate.[28,40,48] The present study did not specifically evaluate this criteria; however, as cases were done in an integrated clinics environment, it is expected that most, if not all, were restored. In addition, although the literature has information on the survival of endodontically treated teeth accordingly to the type of restoration, such level of stratification on the current study would demand a remarkable increase in sample size, and for a factor that is not the main purpose here.

Further studies looking into the outcomes of root canals completed by early learners in dentistry may be necessary, more specifically looking into the technique variations and how they impact the clinical results. Our study is one of the first to look beyond the incidence of procedural errors and, although limited by sample size and the fact that it is a retrospective study, it shows that technological improvements are able to produce similar outcome results when used by dental students.

5 | CONCLUSIONS

We can conclude that novice students using the WOG technique are more prone to over-instrumentation errors than students using the HYB instrumentation technique, thus rejecting the null hypothesis in this topic. However, both groups showed a low incidence of canal transportations, ledges, and instrument separation, and the higher incidence of over-instrumentation in the WOG group did not affect tooth survival, in this case failing to reject the second null hypothesis. The score of the periapical lesion was the only factor that was significantly associated with lower tooth survival.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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