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ORIGINAL ARTICLE

Outcome of secondary root canal treatment filled with Thermafil: a 5-year follow-up of retrospective cohort study

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Abstract

Objectives The aim of the present retrospective cohort study was to assess the 5-year outcome and survival of secondary root canal treatments (2°RCT), exploring the influence of pre-, intra-, and post-operative variables.

Materials and methods One hundred thirty-two endodontically retreated teeth were radiographically and clinically re-examined after 5 years. 2°RCT had been performed during a Masters program following standardized protocols and filled with AH Plus/Thermafil (TF). Pre-, intra-, and post-operative data were collected. The 5-year outcome was blindly evaluated and categorized as *healed*/*diseased* on the basis of the periapical index. Bivariate analysis and chi-square test evaluated the association between outcome and 31 demographic/clinical parameters. Multilevel analysis was performed at both patient and tooth level. Statistical significance was calculated at 5% level.

Results At 5-year evaluation, survival rate was 80% with 7.5% lost for endodontic reasons. Eighty-three percent of the teeth were classified as *healed*. Multilevel analysis identified significant predictors of increased survival: female gender ($p = 0.012$), absence of a pre-operative metal post ($p = 0.017$), conservative apical preparation (diameter size < #35) ($p = 0.039$), teeth restored with a crown ($p = 0.009$), and final PAI (after 5 years) ≤ 2 ($p = 0.001$). Multilevel analysis identified as predictor healing: not being a smoker ($p = 0.048$) and conservative apical preparation < size #35 ($p = 0.037$).

Conclusions Outcome of 2°RCT filled with Thermafil was successful at 5 years, showing a high rate of survived and healed teeth comparable to that reported previously for other obturation techniques.

Clinical relevance Present findings confirm 2°RCT as a valid therapeutic option to retain natural teeth.

Keywords Carrier-based system · Clinical study · Outcome predictors · Secondary endodontic treatment

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Introduction

Treatment outcome is the basis for every decision-making process [1, 2] and even though techniques, equipment, and materials are constantly improving, 2°RCT still remains a challenge for clinicians as demonstrated in the less favorable outcome when compared to initial treatment [3]. Preserving natural teeth as opposed to tooth extraction and replacement is a dilemma clinicians must face routinely [4]. However, 2°RCT should be considered as a first approach in failing endodontic cases [1].

Information on 2°RCT prognosis is controversial [5] as the reported success rates range between 40 and 100% [6]. Persistent intraradicular, extraradicular, or secondary infections are the major causes of failure of both poorly treated and well-treated root canals [7]. According to the European Society of Endodontology [8], indications for 2°RCT include teeth with inadequate root canal filling in presence of apical periodontitis, symptomatic previously treated teeth, inadequate coronal restoration, or indication for bleaching.

Nevertheless, it is extremely arduous to define and categorize 2°RCT outcomes for each clinical scenario in terms of success/failure as clinical and radiographic signs can be unclear.

The root canal filling represents a crucial intra-operative step that can affect the final outcome of endodontic therapies [9]. This applies to both primary root canal treatment (RCT) and 2°RCT. However, the increased difficulty in the case of altered morphology and anatomical irregularities should be considered, often created by a previous RCT [10] compromising the outcome.

Although Thermafil (TF) is recognized as an efficient obturation technique [11], there is a lack of information regarding 2°RCT outcome when using this system. Existing evidence consists of both retrospective [12–16] and prospective [17] clinical outcome studies of RCT filled with Thermafil, reporting a similar success rate to other obturation techniques.

The aim of the present retrospective cohort study was to assess the 5-year survival and healing of 2°RCT conducted in a specialist institution and filled with TF system. Additionally, the influence of pre-, intra-, and post-operative variables on the final outcome was evaluated.

Materials and methods

Follow-up group

Between January and November 2016, a database was created in order to monitor patients attending the Endodontic Clinical Section of the University of Bologna, for the management of painful or asymptomatic periapical periodontitis. In accordance with our Recall Program, 180 patients who had received a total number of 294 2°RCT between 2009 and 2011 were clinically and radiographically examined in full compliance with the World Medical Association Declaration of Helsinki [18]. A signed informed consent was obtained from all the subjects enrolled in the study. Patients with medical conditions such as diabetes, cardiovascular disease, and oncologic history were excluded. Teeth presenting either severe coronal damage, advanced periodontal disease, supporting bridges, or filled with different obturation techniques were excluded.

Follow-up radiographs were obtained at specific recall appointments or during the course of treatment of the adjacent teeth. Subjects that fulfilled the following inclusion criteria were enrolled in the study (n = 81 subjects; 132 teeth): local residents, aged between 18 and 70 years, adequate oral hygiene (plaque index < 20%), previously filled root canals, complete clinical and radiographic records available with a 5-year minimum follow-up (Fig. 1).

Root canal retreatment

Trained postgraduate students and experienced tutors of a Masters program in endodontics at the University of Bologna performed all 2°RCT. The protocol was strictly standardized and only modified on the basis of the filling material identified in the pre-operative radiograph. Each tooth was isolated with a rubber dam (Hygienic Dental Dam, Coltène Whaledent, Cuyahoga Falls, OH USA) before creating a straight-line access. Inadequate coronal restorations and decay were removed using a water-cooled round diamond bur mounted on a high-speed hand piece. Pre-existing crowns were disassembled before rubber dam application. Metal and fiber posts were removed with ultrasonic tips (Start-X Dentsply Maillefer, Ballaigues, Switzerland) under magnification using either a dental operating microscope (Carl Zeiss, Oberkochen, Germany) or dental loupes (EyeMag Pro, Carl Zeiss, Oberkochen, Germany). Root filling material was removed with #2, 3, 4 Gates Glidden burs (Maillefer, Ballaigues, Switzerland) and manual K-files (Maillefer, Ballaigues, Switzerland) aided by the use of solvents for gutta-percha and cement (Endosolv E or Endosolv R Septodont, Cedex, France) until the material was not detectable radiographically or under magnification. In the event of separated endodontic instruments, either removal or bypass of the retained fragments was attempted with ultrasonic tips and hand files under operating microscope. When both attempts failed, the retained instrument was left inside the canal and the accessible part of the canal was treated. Patent canals were then instrumented in step-down sequence with Gates Glidden burs #4, 3, 2 and manual K-files with increments of 1 mm or with ProTaper Universal (Dentsply Maillefer, Ballaigues, Switzerland). The working length was determined at 0.5 mm from the apex using an electronic apex locator (Root ZX, Morita, Tokyo, Japan) and radiographically confirmed. If it was not possible to reach the entire working length, files were used to the point of the canal where the hand file reached. In the case of pre-existing or intra-operative perforations of the pulp-chamber floor, a mineral trioxide aggregate MTA-like cement (Tech BioSealer, Isasan, Italy) was applied and subsequently covered with a light-curing glass ionomer liner (Vitrebond 3M Espe, St. Paul, USA).

Each canal was irrigated with 5–10 ml, 5% NaOCl (Niclor 5, Ogna, Muggiò, Italy) and 1–3 ml, 10% ethylenediaminetetraacetic acid (EDTA) (Tubuliclean, Ogna, Muggiò, Italy). After final irrigation, canals were dried with sterile paper points (Mynol, Milwaukee, WI, USA). Canals with a final apical diameter between ISO size #20 and #45, were filled with Thermafil and AH Plus (Dentsply DeTrey GmbH, Konstanz, Germany). AH Plus sealer was mixed and inserted into the root canal using sterile K-files. Thermafil obturators were selected based on the fitted verifier size and decontaminated for 1 min

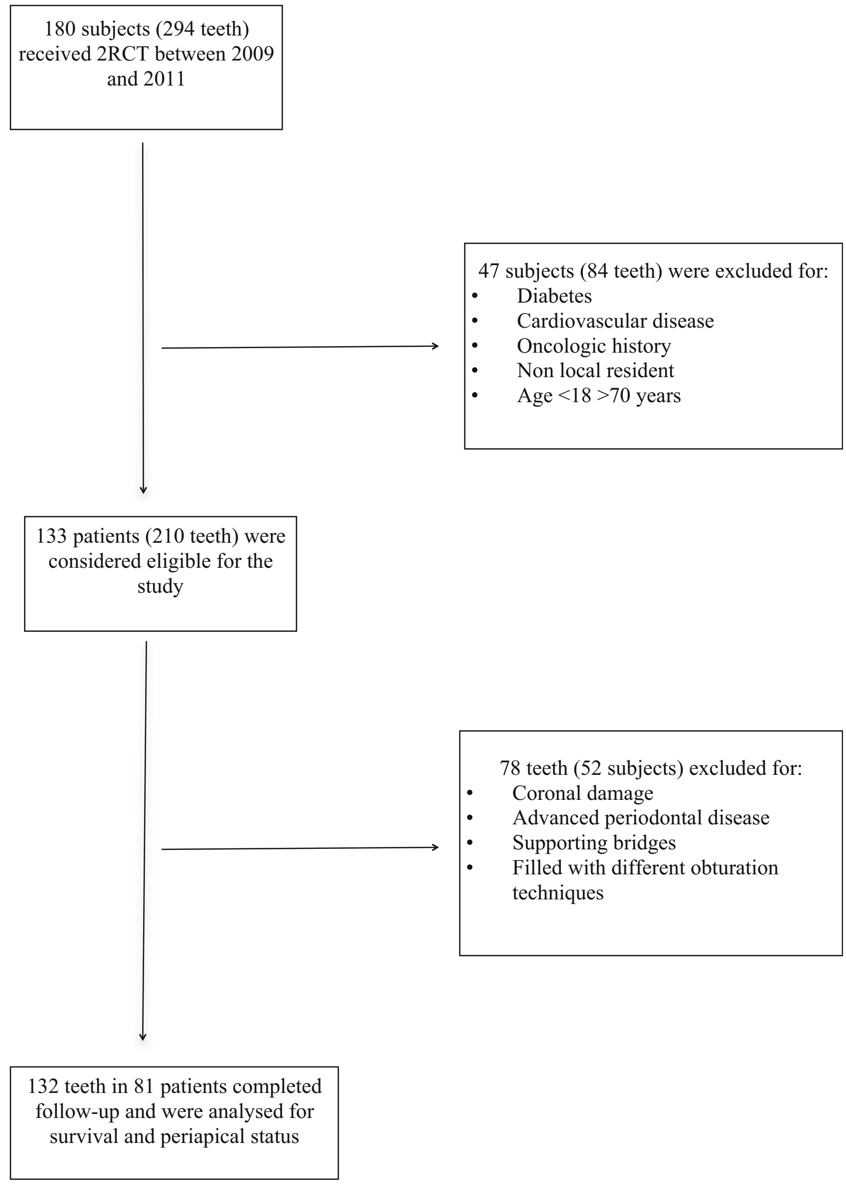

Fig. 1 Flow chart diagram reporting the number of individuals at each stage of the study

with 5% NaOCl, heated in the dedicated oven (ThermaPrep Maillefer, Ballaigues, Switzerland), and inserted with a slow and continuous movement in order to reach the established working length. Apices wider than size #50 were excluded from the study. All treatments were performed and completed in two or more appointments with 7–10 days inter-appointment intervals.

All teeth were temporized with Coltosol (Coltène Whaledent, Cuyahoga Falls, OH, USA) and received a permanent restoration within 2 weeks from root canal obturation. A self-etching dentin bonding agent (Clearfil SE BOND, Kuraray, Tokyo) was gently applied on both dentine and enamel, according to manufacturer's directions. A flowable composite resin and a high-filled composite resin (Gradia Direct, GC, Tokyo, Japan) were layered and photo-cured in the cavity. When considered necessary, a carbon fiber post (Tech 2000 XOP, Isasan, Rovello Porro, Italy) was placed and cemented using Scotchbond 1/Relyx ARC (3M ESPE, St. Paul, MN, USA).

The placement of a provisional resin crown followed by a definitive metal ceramic crown was decided on the basis of the residual tooth structure. The definitive metal ceramic crown was applied within 4–6 months from endodontic therapy. Pre-, intra-, and post-operative radiographs (Dental Intraoral D-Speed Film Kodak, Rochester, NY, USA) were taken using the paralleling technique and only those with proper angulations and development were accepted. The exposure time of each tooth type was standardized to minimize the radiation dose.

Data collection

Demographic variables (age, gender, smoking habit, medical history) were recorded considering the patient as the unit of study whereas clinical variables were collected considering the tooth as the unit of study. For each included tooth the following pre-, intra-, and post-operative data were collected: symptoms, treatment date (clinical parameters), and presence of periapical radiolucency, initial periapical index (PAI), previous restoration, and length and quality of root canal filling (radiographic parameters) (Tables 1, 2, 3, 4). Signs and symptoms related to the initial diagnosis, suggested the indication for 2°RCT and endodontically treated teeth were categorized as follows: (i) treated teeth with a periapical lesion and (ii) treated teeth without a periapical lesion (retreated for prosthetic reasons).

PAI [19] was used to score each radiograph. For multirooted teeth, the root with the worst outcome became the outcome of the tooth. Radiographs were scored by two independent examiners calibrated in the use of the PAI score. In case of disagreement, a third calibrated observer was consulted for joint evaluation.

At the 5-year follow-up, retreated teeth were categorized [20] in two groups: *healed* (PAI ≤ 2 and no symptoms or clinical signs of illness) [19, 21], or *diseased* (PAI ≥ 3, presence of symptoms or clinical signs of illness). Cause and timing of extractions were recorded.

Statistical analysis

Sample size was determined on a random pilot sample of 50 patients (50 teeth); Cox regression identified post-endodontic restoration with crown (survival rate at 5-year, 80%) as prognostic factor of survival in comparison with direct restorations (survival rate at 5-year, 60%). According to a non-inferiority design with a non-inferiority margin of 10% and anatomical guided ratio of two samples equal to 0.75, given that direct restorations are usually applied to anterior teeth and crowns to posterior teeth, with a power of 90% at an α level of 0.05 for a two-sided test, at least 77 teeth were needed. One hundred thirty-two teeth were collected.

Univariate (means or proportion according to quantitative or categorical level of measurement) and bivariate analysis (contingency tables associating demographical/clinical, pre-, intra-, and post-operative parameters) was carried out; chi-square or Fisher test were applied aiming to individuate significant predictors of healing and survival.

The inferential analysis was conducted by creating multilevel linear regression models (mixed effects model) applying a binary logistic function for the healing outcome and an interval censored survival function for the survival outcome. Factors associated with the outcomes were used as covariates in the multilevel model and explored at patient and tooth level. Kaplan-Meier survival analysis was used to account for the extracted teeth. All tests were interpreted at 5% level of significance.

Table 1 Descriptive analysis of the demographic parameters of the study cohort. Significant associations highlighted with bold typeface

Variables		Treated	Survival			Healed		
		n	*n*	%	*p* value	*n*	%	*p* value
Demographic and medical parameters								
	Gender				0.009			0.646
Female		48	63	89		60	85%	
Male		33	42	69		49	80%	
	Smoke				0.013			0.034
Yes		19	21	64		23		
No		62	84	85		86		
	Bisphosphonates				1.00			
Yes		9	9	82		9	82%	
No		72	96	79		100	83%	
	ASA							0.247
ASA 1		50	69	83		71	85%	
ASA 2–4		31	36	73		38	78%	
	Age				0.811			0.847
< 30		5	4	80		4	80%	
30–50		28	42	82		41	80%	
> 50		48	59	78		64	84%	
Total		81	105	80%		109	83%	

Table 2 Descriptive analysis of pre-operative parameters of the study cohort. Significant associations highlighted with bold typeface

	Variables	Treated	Survival			Healed		
		n	*n*	%	*p* value	*n*	%	*p* value
	Tooth location				0.5			0.564
Maxilla		7656	62	82%		64	84%	
Mandible			43	77%		45	80%	
	Tooth type				0.196			0.121
Anterior		11	8	73%		10	91%	
Premolar		49	43	88%		44	90%	
Molar		72	54	75%		55	76%	
	Number of canals				0.093			0.058
One or two canals		58	50	86%		52	90%	
Pluriradicular		74	55	74%		57	77%	
	Previous restoration				0.317			0.224
None		7	5	71%		6		
Amalgam		15	12	80%		10		
Composite		54	47	87%		48		
Crown		56	41	73%		45		
	Presence of post				**0.004**			0.295
Absent		99	85	86%		84	85%	
Metal post		28	16	57%		22	79%	
Fiber post		5	4	80%		3	60%	
	Previous fracture				1.00			0.918
Yes		22	18	82%		18	82%	
No		110	87	79%		91	83%	
	Previous perforation							0.05
Yes		10	5	50%	0.111	6	60%	
No		122	99	81%		103	40%	
	Perforation localization				0.153			0.108
Coronal third		6	3	50%		2	33%	
Middle third		3	3	100%		3	100%	
Apical third		1	0	0%		1	100%	
	Canals pre-retreatment				0.408			0.653
Patent		21	16	76%		16	76%	
Calcified		55	46	85%		47	85%	
Ledged			43	75%		46	82%	
	Separated instruments				0.344			0.694
Yes		125	98	78%		103	82%	
No		7	7	100%		6	86%	
	Localization separated instruments				na			0.695
Coronal		0	0	0%		0	0%	
Middle		6	6	100%		5	88%	
Apical		1	1	100%		1	77%	
	Quality of previous root filling				**0.001**			**0.021**
Adequate		11	4	36%		54%		
Not adequate		98	83	85%		88%		
Missed canal		22	18	82%		77%		
	Percussion test				0.155			**0.004**
Positive		67	50	75%		49	73%	
Negative		65	55	85%		60	92%	

Table 2 (continued)

	Variables	Treated	Survival			Healed		
		n	*n*	%	*p* value	*n*	%	*p* value
	Previous pain				0.500			**0.015**
Yes		56	43	77%		41	73%	
No		76	62	82%		68	89%	
	Periapical Radiolucency				0.408			**0.028**
Yes		89	69	78%		69	78%	
No		43	36	84%		40	93%	
	PAI initial				0.516			**0.013**
≤ 2		58	48	83%		53	91%	
≥ 3		74	47	77%		56	75%	
	Occlusal contact				0.500			0.462
Yes		129	103	80%		107	*83%*	
No		3	2	67%		2	67%	
Total		132	**105**	**80%**		**109**	**83%**	

na not available

Results

One hundred thirty-two teeth met the inclusion criteria and were included in the final analysis; the post-endodontic restoration two-group sample size ratio was of 0.25. Of the 81 included subjects (48 females and 33 males, mean age 45 years, range 30–50 years, recall rate 45%), 62 were non-smokers, 48 were systemically healthy (Table 1).

An excellent inter and intra-observer agreement was obtained guaranteeing the reliability of the outcome evaluation;

Table 3 Descriptive analysis of intra-operative parameters. Significant associations highlighted with bold typeface

	Variables	Treated	Survival			Healed		
		n	*n*	%	*p* value	*n*	%	*p* value
	Instrument type				**0.023**			0.197
Hand files		114	87	76%		92	81%	
NITI		18	18	100%		17	94%	
	Curvature radius				0.577			0.558
Straight		59	47	80%		51	86%	
Moderate		69	54	78%		55	80%	
Severe		4	4	100%		3	75%	
	Apical diameter				**0.001**			**0.012**
< 35		72	65	90%		65	90%	
≥ 35		60	40	67%		44	73%	
	Instrument separation				1.00			1.00
Yes		3	3	100%		3	100%	
No		129	102	79%		106	82%	
	Root filling end							0.585
Underfilled		27	21	78%		21	78%	
Adequate		70	56	80%		60	86%	
Overfilled		35	28	80%		28	80%	
	Flare-up				0.360			0.143
Yes		8	5	62%		5	62%	
No		24	100	81%		104	84%	
Total		132	**105**	**80%**		**109**	**83%**	

Table 4 Descriptive analysis of post-operative parameters. Significant associations highlighted with bold typeface

	Variables	Treated	Survival			Healed		
		n	n	%	*p* value	n	%	*p* value
Post-operative parameters								
	Post-endo				**0.005**			**0.046**
Direct		28	17	61%		19	68%	
Crown		104	88	85%		90	87%	
	Post placement				0.461			0.012
Yes		42	35	83%		38	91%	
No		90	70	78%		71	79%	
	PAI final				**0.0001**			**0.0001**
≤ 2		109	99.0	91%		109	100%	
≥ 3		23	6.0	26%		0	0%	
Total		132	**105**	**80%**		**109**	**83%**	

kappa statistic were respectively 0.937 ± 0.062 (p = 0.0001) and 1.00.

The total 5-year survival rate was 80%. A total of 17/27 teeth were extracted for non-endodontic reasons (two were lost due to periodontal disease and 15 due to vertical root fractures/non restorability). Therefore, extraction due to endodontic pathology accounted for 10 teeth. Median survival time was of 52 months (interquartile range 6–84 months) (Fig. 2). Results of bivariate analysis concerning tooth survival are shown in Tables 1, 2, 3, 4 and revealed significant associations between survival and the following variables: gender, smoke, presence of pre-operative post, previous root filling quality, instrument type, size of final apical diameter, post-endodontic restoration type, and final PAI. Multilevel analysis identified as significant predictors of survival: female gender (p = 0.0129), presence of fiber post (p = 0.017), final apical diameter < 35 (p = 0.039), post-endodontic restoration with crown (p = 0.009), and final PAI ≤ 2 (p = 0.001) (Table 5).

Of the 132 analyzed teeth, 83% were considered *healed* (n = 109) and 17% *diseased* (n = 23). Bivariate analysis revealed significant associations between a healthy status and nine independent variables (Tables 1, 2, 3, 4): smoking, previous root filling quality, a positive percussion test, reason for treatment, previous pain, periapical radiolucency, initial PAI, size of final apical diameter, and post-endodontic restoration type. Multilevel analysis identified as predictors of 2°RCT healing: being non-smoker (p = 0.048) and a final apical diameter < 35 (p = 0.037) (Table 6). Complications were divided between perforations (12 teeth) and crown fractures (13 teeth); however, they did not influence significant survival

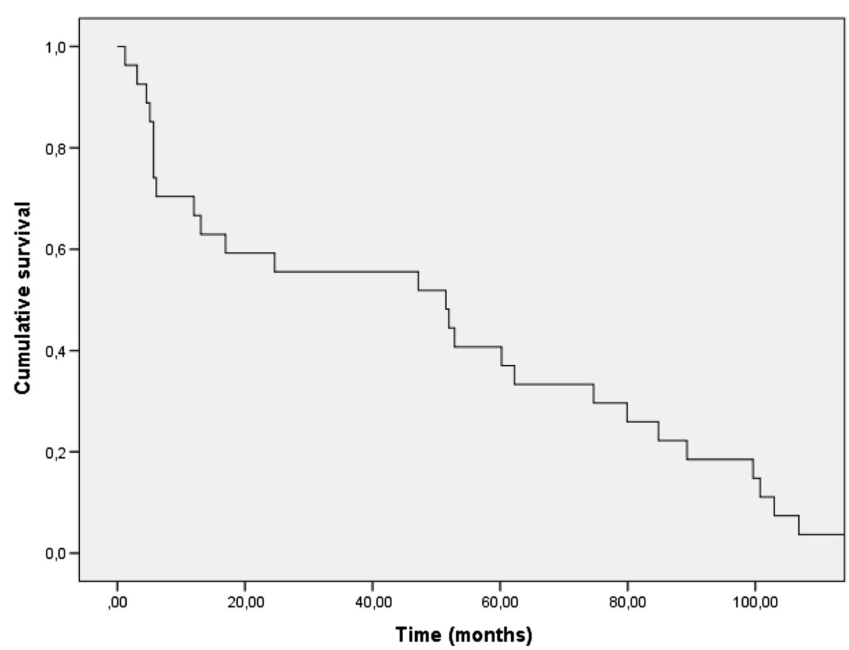

Fig. 2 Kaplan-Meier survival curve

Table 5 Multilevel model investigating variables associated with survival outcome (Akaike information criterion 64.07)

Parameter	Coefficient (standard error)	P =	95% confidence interval
Male (reference category: female)	−1.036 (0.398)	0.012	−1.834;−0.239
Apical diameter < 35 (reference category: > = 35)	0.544 (0.370)	0.039	0.043–1.525
Presence of pre-operative post metal (reference category: fiber)	−2.742 −1.115	0.017	−4.975;−0.509
Post endo direct (reference category: crown)	−1.173 (0.431)	0.009	−2.036;−0.309
PAI one-two (reference category: three-five)	2.743 (0.543)	0.0001	1.655–3.831

($p = 0.202$) or healing rate ($p = 0.543$). During the observation period, seven teeth were subjected to further treatment, one underwent endodontic surgery, and six were hemi-sectioned.

Discussion

The present retrospective study assessed the 5-year survival and success of 2°RCT filled with Thermafil, investigating outcome predictors. Multilevel modeling was used to analyze clinical data, since teeth are clustered and correlated within the same patient [22].

Even though several studies have reported a similar survival rate for RCT and 2°RCT [23–25] many others have documented a less favorable prognosis of 2°RCT [2, 5, 10, 26–29], especially when associated with pre-operative presence of apical periodontitis [1, 16, 25, 30, 31]. This unfavorable outcome is mainly related to the difficulty in elimination of the microflora [32] characterized by Gram-positive *Enterococcus faecalis* [7], other Gram-negative anaerobic bacteria and *Candida albicans* [30, 33]. Moreover, intricate and altered anatomies and complex operative procedures aiming to remove contaminated debris and filling material [34] make 2°RCT procedures challenging.

The use of an efficient obturation system to fill and seal the canal space is a crucial factor influencing the clinical outcome. Prospective clinical investigations have demonstrated that TF simplifies the insertion and compaction of gutta-percha [11], provides similar results to other conventional obturation techniques [16, 17], and ensures a predictable sealing when used with an epoxy-resin cement [13, 17, 35].

While technology has provided countless new instruments and materials to achieve better results in RCT, it is interesting that the reported success rates have not increased over the last four to five decades [36]. A possible explanation could be the selection of more complex cases supported by confidence in better skills of specialized clinicians and by the tendency to preserve natural teeth [36]. The overall healing rate of the present study, conducted to assess the impact of an obturation technique on 2°RCT prognosis, was 83%. It should be emphasized that our findings are consistent with previous clinical studies reporting the use of other obturation techniques [1, 31, 37], the same carrier-based system [16], and with a systematic review [38] on 2°RCT.

The present study was conducted in a University Clinical Section specialized in endodontics, with the aid of novel techniques and materials. The relatively low recall rate can be explained considering the fact that a large portion of the treated population is transient and represented by students or discontinuers. However, it was higher than the percentage recalled by other clinical studies [20, 39]. Treatments were carried out by postgraduate students and tutors, following strictly standardized protocols concerning diagnosis, treatment, and follow-up. It is important to highlight that treatments performed in teaching and specialistic facilities can be affected by a more difficult case selection as a result of the tertiary referral nature to this type of institution [40], and for this reason, results must be interpreted with caution. RCT performed by specialists is more than 10% successful than treatment provided by general dentists [41]. This was also confirmed by Torabinejad et al. [38] that documented/concluded operators' training level and experience as an important factor influencing 2°RCT final outcome. Specialist involvement was reported in only one-fourth of the published clinical studies [24]. Furthermore, the need to reassess 2°RCT outcomes performed by specialists with current techniques has been expressed.

In our research, 2°RCT total survival rate was 80% at 5 years, lower than other rates previously reported (88–95%) [16, 25, 41, 42] referring invariably to RCT and 2°RCT. This discrepancy can be attributed to the nature of the present

Table 6 Multilevel model investigating variables associated with 2°RCT healing (Akaike information criterion 92.55).

Parameter	Coefficient (standard error)	P =	95% confidence interval
Smoking (reference category: no smoke)	−1.178 (0.583)	0.048	−2.346;−0.011
Apical diameter < 35 (reference category:> = 35)	1.214 (0.569)	0.037	0.073–2.354

research considering only 2°RCT. In contrast, the survival rate for 2°RCT treatments reported in a recent study of the same group [16] was 79%, almost identical to the 80% reported here. Moreover, endodontically retreated teeth are more likely to be extracted due to fractures, non-restorability, or periodontal reasons rather than as a result of complications related to endodontic reasons. In fact, 55% of extracted teeth (15/27) were lost for fractures. This could be associated with the lack of residual dental structure or with a possible degradation of the collagen fibrils in root dentin after clinical function [43], compromised from both RCT and 2°RCT procedures. The frequency of perforations in the initial treatment or during the retreatment was low (10 pre-operative and 12 intra-operative) and did not significantly affect the healing rate or survival.

Analyzing the demographic parameters, the survival rate of retreated teeth for female patients was significantly higher than those for male patients. Interestingly, few studies have found a significant association between endodontically treated teeth survival and gender [9, 38, 44–46].

Many operative factors were related to tooth survival in the descriptive analysis; however, multilevel model identified the final coronal restoration as a relevant predictor of survival with a better prognosis for teeth restored with full cuspal coverage than with direct restorations. Other clinical studies on the survival of RCT have confirmed these findings [13, 42, 45, 47–49]. Crown placement was strongly suggested in case of severe structural loss due to the increase of the fracture risk; however, the final decision was left to the patient.

The final size of apical preparation is a controversial topic, attracting much interest [50] in clinical research. Hoskinson et al. [39] reported that the success rate for a conservative apical preparation (size 20–30) was higher (85%) than that for large apical preparations (size 35–90) (56%). Both Ng et al. [25] and Saini et al. [51] have concluded that over-enlarging the canal is unnecessary. In accordance with these results, an interesting finding in our study was a significantly lower success and survival rate of teeth with a final apical preparation of size 35 or wider. This can be explained by aberrant large apices, demonstrating transportation/stripping caused by overaggressive instrumentation [52, 53] or root resorptions, often present in previously treated teeth [10]. It would be interesting to clarify whether this aspect is related to a difficult apical management with a carrier-based obturation technique.

When a post was present pre-operatively, it was found to have a significant effect on the survival rate [54]; retreated teeth presenting a previous metal post were associated to a higher extraction risk due to vertical root fracture. This could be due to major loss of tooth structure that metal posts require during placement and removal and/or to the corrosion mechanisms that occur in the oral environment inducing expansion stresses and consequent physical damages to the root [55].

An interesting finding was that patients presenting systemic diseases did not present differences in healing rate, as found by Azim et al. [56].

Despite the paucity of evidence connecting smoking with endodontic disease, present results revealed a significant association between this habit and a reduced chance of periapical healing. Smoking appears to be one of the most significant prognostic factors in the progression of marginal periodontitis [57] and has been previously reported as a statistically significant risk factor for developing apical periodontitis [21, 58]. Its role in affecting bone healing has been documented [57] and therefore a similar effect on the apical periodontium could be hypothesized. This speculation has also been confirmed by a recent study [46] that found smoking as a significant predictive factor for a worse outcome in endodontics. However, considering that our research did not aim to evaluate the impact of smoking on 2°RCT outcome, these interesting findings require further investigation.

Conclusions

Within the limitations of the retrospective nature of this study, the 5-year survival rates of 2°RCT filled with TF suggested a comparable prognosis to that reported previously for other obturation techniques. The main reason for extraction was connected to root fractures and not to complications related to endodontic reasons. Further studies are required to evaluate the influence of smoking on 2°RCT outcome. It can be concluded that 2°RCT performed with contemporary materials and equipment and by specialists represents a valid therapeutic option to retain natural teeth.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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