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Cohort study

THE PROGNOSIS OF ROOT CANAL THERAPY: A 20-YEAR FOLLOW-UP AMBISPECTIVE COHORT STUDY ON 411 PATIENTS WITH 1169 ENDODONTICALLY TREATED TEETH

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PURPOSE To evaluate the 20-year prognosis of endodontically treated/re-treated teeth in a population with multiple patient/tooth/site risk factors, and to investigate the prognostic factors that could predict the long-term outcome of endodontic therapy.

MATERIALS AND METHODS This ambispective cohort study included patients who received primary/secondary root canal therapy from 1986 to 1998 performed by a single operator in a private practice. Outcomes measures were: tooth survival; clinical and radiographic success, as assessed by the treating clinician and an independent outcome assessor; and complications, as evaluated 20 years after treatment. Descriptive statistics, life table and Cox regression analyses for survival were fitted.

RESULTS Four hundred and eleven patients (59% affected by advanced periodontitis) with 1169 endodontically treated teeth were identified (703 treatment, 466 retreatment). Drop-outs at 20-year follow-up were 128 patients (31.1%) with 388 (33.2%) teeth. Forty teeth (3.4%) in 30 patients experienced endodontic complications, subsequently successfully treated. Clinical and radiographic evaluation revealed: complete clinical success in 542 teeth (69.7%), partial success in 10 (1.3%), partial failure in 75 (9.6%), and failure in 151 (19.4%) (10 extracted for endodontic reasons, 58 due to periodontitis, and 58 vertical fracture). Life table analysis revealed 86% tooth survival at 20-year follow-up. The chance of survival decreased with increasing patient age (P = 0.006). Re-treated teeth had better survival than treated teeth (P = 0.024) Canines and premolars had better chances of survival than incisors (P = 0.002 and P = 0.015, respectively). Teeth treated at two sittings (with intermediate medication) had reduced chances of survival as compared to teeth treated at one sitting (P = 0.027). Teeth treated for the first time for endodontic reasons exhibited a better chance of survival than teeth treated for periodontal and prosthetic reasons (P = 0.012).

CONCLUSIONS The 20-year prognosis of endodontically treated/re-treated teeth as part of multidisciplinary rehabilitation of patients affected by advanced periodontitis is good. Aging, two-stage endodontic treatment, and endodontic treatment for non-endodontic reasons are important predictors of failure.

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INTRODUCTION

Endodontic treatment aims to preserve the natural dentition in the oral cavity by preventing and treating apical periodontitis once endodontium contamination is established. Dental implants represent reliable substitutes when teeth are missing or teeth are severely compromised. However, the multiple therapeutic procedures (endodontic, periodontal, restorative and prosthetic treatments) involved present high biological and economic cost[1,2].

This raises important questions concerning the best treatment option for severely compromised teeth, and the long-term performance thereof [1,3,4].

Considering the endodontic prognosis alone, root canal therapy (RCT) is known to be a successful, highly reliable and non-invasive treatment[5].

However, studies reporting the long-term outcomes (more than 10 years of follow-up) of endodontic therapy in severely compromised teeth and the factors influencing its effectiveness remain very rare, and the scientific evidence is still limited[3,6].

In particular, the impact of endodontic therapy on the overall long-term prognosis of teeth with restorative and prosthetic risk factors in patients susceptible to periodontal disease still remains undefined.

Therefore, the aim of this ambispective cohort study was to evaluate the outcomes of endodontic treatment over 20 years of follow-up in patients with advanced periodontal disease, and in teeth with multiple specific site/tooth risk factors, and to investigate the prognostic factors which could influence the long-term success of primary (treated for the first time) and secondary (re-treated) endodontic therapy.

MATERIALS AND METHODS

The present investigation is the continuation of a previously published study with 10-year follow-up data[7]. The difference between the two studies in the number of teeth included (1169 instead of 1175) is due to a calculation error detected in the interim. Specifically, it was noticed that in the first publication six teeth were counted twice in two patients (1 tooth extracted, 4 teeth healed, 1 tooth improved).

The study sample comprised any patient who had at least one tooth endodontically treated or re-treated by a single operator (F.F.) in a private practice between 1986 to 1998. The study was ambispective (retrospective until 2007 and prospective thereafter) prospectively.

The investigation adhered to STROBE Statement guidelines (www.strobe-statement.org) for observational studies. Informed consent was obtained from all participants included in the study after informing them about the procedures involved. In patients under 18 years of age, consent was obtained from a parent or legal guardian.

Endodontic therapy

Before endodontic therapy, periapical radiographs were taken of each tooth using the long-cone technique and a Rinn XCP film holder (Dentsply Sirona, Charlotte, NC, USA). For multi-rooted teeth, two preoperative periapical radiographs were taken from different angles to better evaluate root canal anatomy. Teeth with uncertain pulp vitality were subjected to sensitivity tests (cold, warm gutta-percha, and in a few cases cavity test).

Immediately before endodontic treatment, teeth were cleaned using an abrasive paste, isolated with a rubber dam, and disinfected with a cotton pellet soaked in 3% sodium hypochlorite. The pulp chamber was accessed using a water-cooled diamond bur (Intensiv 6916, Grancia, Switzerland). In root canal treatments performed before 1991, the working length was determined on periapical radiographs taken using the parallel technique after inserting a file into the canal, 0.5 mm coronally from the radiographic apex. Thereafter, an electronic apex locator was used (Neosono-D, Amadent Medical and Dental Co., Cherry Hill, NJ, USA; and after 1996, Root ZX, Morita Corp., Kyoto, Japan) at the "0" reading position.

Two preparation and obturation techniques were used: Schilder's technique between 1986 and 1993, and the crown-down technique from 1994 onwards[8-10]. For Schilder's technique[8,9], all canals were prepared with stainless steel files and root-filled with an adequate gutta-percha cone, adapted to the apical diameter, inserted with a small quantity of sealant (PCS, Kerr, Orange, CA, USA), and compacted vertically using heat carriers (Schilder spreaders size OP and OOP, Hu Friedy, Chicago, IL, USA). From 1991 onwards, Touch'n Heat was used for the purpose (Analytic Technologies, Redmond, WA, USA). Back-packing was performed manually in accordance with Schilder's technique prior to 1991[8], and driven by Obtura syringe thereafter (Obtura Spartan, Foothill Ranch, CA, USA).

For the crown-down technique[10], the coronal third of the canal was enlarged with Gates-Glidden drills (Maillefer, Balagues, Switzerland), while the remaining portion was filed using pre-curved stainless-steel Hedstrom files (Maillefer) with decreasing diameters from the middle to the apical third, without apical pressure. Standardized gutta-percha points were used to obturate the canals, choosing the cone with the diameter fitting the apical preparation. A cold lateral-compaction technique was used. The master cone was inserted into the canal with a small quantity of sealant (PCS); then accessory gutta-percha cones where laterally compacted with spreaders. Coronal excess of gutta-percha was removed, and vertically compacted using a heat carrier.

For both techniques, sodium hypochlorite 3% was used to rinse the canals after each instrument size. Ultrasound (EMS Piezon Master 400, EMS 1260, Nyon, Switzerland) was used to clean the canals for the crown-down technique only. In calcified canals, RT1 ultrasonic tips were used in association with ethylenediaminetetraacetic acid (EDTA) (RC PREP, Premier, Philadelphia, PA, USA) to remove calcifications. Canals were dried with sterile paper cones.

Upon completion of canal filling, the access cavity was temporized with Cavit W (3M ESPE, Seefeld, Germany), and definitively filled within 15 days to 1 month.

In all the teeth planned to be used as abutments for periodontal-prosthetic rehabilitations, the access cavity design and root canal preparation were very conservative to allow maximum preservation of tooth structure[11].

Between 1986 and 1993, calcium hydroxide was used, for 1 week in most cases, as intermediate medication in canals with persistent exudation. From 1994 onwards, treatment of symptomatic teeth, teeth with periradicular radiolucencies, and canals with exudation was completed over the course of two appointments. Calcium hydroxide paste was used, mainly for 1 week, as medication between endodontic sessions. In re-treated teeth with radiolucencies, the dressing was performed with iodoform paste (Ogna Lab, Muggiò, Italy) for 1 week.

Follow-up protocol

All patients were recalled for a scaling/root planing session every 3, 4 or 6 months, depending on the periodontal and dental risk factors. The treating clinician (F.F.) checked the clinical conditions of the treated teeth annually. The first radiographic control was performed at 1 year for all endodontically treated teeth (at 6 months only for teeth that had been symptomatic following treatment and/or displayed preoperative periradicular radiolucency). Following the first year, and up to the final 20-year evaluation, radiographic check-ups were scheduled every two years or more, in line with ADA recommendation for patients with multiple risk factors[12].

All patients were invited to attend the 20-year post-endodontic treatment evaluation. The reason for and date of drop-outs were recorded, as well as the date of the last clinical/radiographic assessment for the patients who did not attend the final 20-year follow-up appointment.

Outcomes

The outcomes recorded were the following.

- Tooth survival, as assessed by the treating clinician (F.F.) during the follow-up check. Reasons for any failure were recorded. Extracted teeth or roots were examined under 4.5x magnification, and in the event of persistent diagnostic doubts, coloured with methylene blue to disclose vertical root fractures.
- Treatment success, as assessed clinically by the treating clinician (F.F.) and radiologically by one blinded independent and experienced assessor (P.B.) in the following way: complete success (asymptomatic tooth with complete absence of visible periradicular radiolucency in periapical radiographs); partial success (reduced radiolucency but tooth asymptomatic and in perfect function); partial failure (not reduced/worsened radiolucency or radiolucency not present before the treatment but tooth still asymptomatic and perfectly functional), and failure (tooth that needed to be extracted for endodontic or other reasons[13]. Multi-rooted teeth were scored according to the root having the worst outcome.

  Periapical radiographs taken up to 2007 were examined on a radiograph dental viewer using a magnifying lens with 4x magnification in a partially darkened room. Thereafter, digital periapical radiographs were taken and evaluated on a computer screen. Prior to the radiographic evaluation, the blind independent assessor was calibrated.
- Complications, as assessed by the treating clinician (F.F.). Any endodontic or suspected endodontic complication, such as periapical abscess or clinical situations resembling acute endodontic infection with sulcular drainage and rapid increase in probing occurring over the 20-year follow-up period was recorded and is reported. When the complication precluded maintaining the tooth, the consequent extraction was recorded as a failure, and no longer considered a complication. Successfully treated complications on teeth subsequently extracted for other reasons than the complication itself have also been reported.

Statistical analysis

Descriptive statistics are used to report data for patients (sex, age, periodontal risk, failure and drop-out) and teeth (anatomy, position, pre-operative conditions, failure and dropout). Information on the type of endodontic therapy, presence of intermediate medication, reason for drop-out, and cause of failure and complications was also collected and tabulated. Life table statistics were used to determine tooth survival rates at 20 years, adjusting data for drop-outs.

Cox proportional hazards models were fitted for the survival time up to failure (tooth extraction), taking into account the clustering of teeth within patients (multilevel regressions). The multivariate model included the following variables: patient's age, type of endodontic treatment (treatment vs. re-treatment), preoperative radiolucency (presence of radiolucency vs. absence of radiolucency), endodontic technique (Schilder step-back technique with warm vertical condensation of gutta-percha vs. crown-down technique with lateral condensation of gutta-percha), intermediate medication (medication vs. no medication), type of tooth (incisors, canines, premolars, molars, wisdom teeth), initial treatment reason (endodontic infection vs. periodontal or prosthetic needs), and re-treatment reason (symptoms and/or radiolucency *vs.* inadequate root canal filling or leakage from the endodontic space without radiolucency).

Significance was defined as two-sided $P<0.05$. All statistical analyses were performed using Stata 13 software (StataCorp).

RESULTS

In total, 411 patients were consecutively treated: 250 females (60.8%) and 161 males (39.2%). Age at the time of endodontic treatment ranged between 8 and 86 years (mean 43.5 years). The total number of endodontically treated teeth was 1169 (3764 canals): 703 (60.1%) teeth were treated endodontically for the first time, whereas 466 (39.9%) teeth were re-treated. Distributions of tooth type and number of canals are presented in **TABLE 1** and **TABLE 2**, respectively, while reasons for treatment and re-treatment are shown in **TABLE 3**.

Among all the included teeth, all vital teeth (n = 528) (45.2%) were treated in a single session. Out of the 175 (15.0%) necrotic teeth, 126 were treated without intermediate medication, and 49 were treated with intermediate medication. Finally, in the 466 (39.9%) re-treated teeth, 256 were treated without intermediate medication and 210 were treated with intermediate medication.

TABLE 1 TOOTH TYPE DISTRIBUTION

Type of tooth	Number of teeth (percentage %)
Incisors	201 (17.2)
Canines	96 (8.2)
Premolars	287 (24.5)
Molars	543 (46.5)
Wisdom teeth	42 (3.6)
Total	*1169*

TABLE 2 TEETH DISTRIBUTION BY NUMBER OF CANALS*

Number of canals	Number of teeth (percentage %)
1 canal	478 (40.9)
2 canals	221 (18.9)
3 canals	368 (31.5)
4 canals	100 (8.5)
5 canals	2 (0.2)
Total	*1169*

**Resected molars contributed to the total number of canals only by those which were retained*

TABLE 3 REASONS FOR ENDODONTIC TREATMENT/RETREATMENT

Reasons for endodontic treatment	Number of teeth (percentage %)
Endodontic: irreversible pulpitis	175 (24.9)
Endodontic: pulp necrosis without visible radiolucency	46 (6.5)
Endodontic: pulp necrosis with visible radiolucency	129 (18.4)
Periodontal: rhizotomy/rhizectomy	211 (30.0)
Prosthetic: not in axis for prosthetic preparation	78 (11.1)
Periodontal: excessive tooth sensitivity*	64 (9.1)
Total	*703*
Reasons for endodontic retreatment	**Number of teeth (percentage %)**
Symptoms without visible radiolucency	3 (0.6)
Radiolucency with or without symptoms	196 (42.1)
Inadequate root canal filling (underfilling, etc.)	151 (32.4)
Leakage of the endodontic space	116 (24.9)
Total	*466*

**After non-surgical/surgical periodontal therapy*

Two hundred and forty-three patients (59.1%) within this cohort had advanced periodontitis (at that time defined as "at least one tooth having one pocket probing depth of 6 mm or deeper following non-surgical cause-related periodontal therapy"). Endodontic treatment in these patients was mostly due to periodontal therapy, such as root resection therapy in furcated molars or excessive and persistent dental sensitivity following non-surgical/surgical periodontal procedures[14].

Nine hundred and seventy-one (83.1%) teeth were used as fixed prosthesis abutments for periodontal purposes (root resection/aesthetic requirements) or due to tooth structure loss caused by extensive caries or crown fractures, while 198 (16.9%) teeth were simply built-up with amalgam or composite fillings and gold onlays/overlays.

At 20 years, 128 (31.1%) patients with 388 teeth (33.2%) had dropped out of the study. Thirty-six patients (28.1%), contacted by phone, had moved away but reported no symptoms or dental problems on the treated teeth, 15 patients (11.7%) were unwilling to attend, 47 patients (36.7%) did not respond, 23 patients (18.0%) died, and 7 patients (5.5%) were severely ill. Reasons for drop-out are listed in **TABLE 4**.

Over the 20-year follow-up, 30 patients (7.3%) experienced 41 complications in 40 teeth (3.4%). Out of the 40 teeth, 39 presented one complication and 1 was affected by two complications. Twenty teeth developed a complication within 2 years, and 14 teeth between 2 and 7 years after the endodontic treatment (**TABLE 5**). After 8 years, few complications were observed, only two being truly endodontic in nature.

All the complications were successfully resolved via apicectomy in 17 teeth, non-surgical re-treatment in 13 teeth, rhizectomy in 8 teeth, and external root resorption obturation in 1 tooth. In 3 patients, 8 teeth with persistent asymptomatic radiolucency were re-treated after 1 year, since they were scheduled to be used as prosthetic abutments. One lower molar experienced 2 complications: the first treated via apicectomy of the mesial root during the first year, and the second via rhizectomy of the same root 14 years later.

Out of all 778 teeth (283 patients) that completed the 20-year follow-up, 542 (69.7%) were considered a complete clinical and radiographic success, 10 (1.3%) a partial success, 75 (9.6%) a partial failure, and 151 (19.4%) were extracted (failure). The 20-year radiographic controls for three teeth were missing, even though the patient did not drop out and the teeth were not extracted; therefore, radiographic estimation of success could not be performed in this case.

One hundred and fifty-one teeth (19.4%) in 97 patients were extracted. One patient lost 13 teeth, two patients lost 8 and 7 teeth respectively, three patients lost 4 teeth each, and all the other patients lost 1 to 3 teeth. Reasons for tooth extraction and their distribution across

TABLE 4 REASONS FOR DROP-OUT AT THE 20-YEAR FOLLOW-UP

Reason	Number of patients (percentage %)
Unable to contact	47 (36.7)
Unwilling to attend	15 (11.7)
Moved away	36 (28.1)
Died	23 (18.0)
Severely ill	7 (5.5)
Total	*128*

TABLE 5 NUMBER AND TYPE OF ENDODONTIC COMPLICATIONS BY YEAR. THIRTY PATIENTS HAD 40 TEETH HAVING 41 COMPLICATIONS (ONE TOOTH WITH 2 COMPLICATIONS: AT 1 YEAR AND AT 15 YEARS)

Year	Frequency	Percentage	Symptoms
0	7	17.1	6 symptomatic, 1 endodontic abscess
1	13	31.7	6 persistent radiolucencies*, 7 endodontic abscesses
2	5	12.2	4 symptomatic, 1 endodontic abscess
4	2	4.9	1 endodontic abscess, 1 endo-perio abscess (external root resorption)
6	1	2.4	1 endodontic abscess
7	4	9.76	4 endodontic abscesses
8	2	4.9	2 symptomatic
13	1	3.1	1 endodontic abscess
15	2	4.9	1 endodontic abscess, 1 endo-perio abscess (vertical root fracture)
16	1	2.4	1 endo-perio abscess
18	1	2.4	1 endo-perio abscess (vertical root fracture)
19	1	2.4	1 endo-perio abscess
20	1	2.4	1 endo-perio abscess (vertical root fracture)

**Teeth retreated for persistent radiolucency before final prosthetic restoration*

years are reported in **TABLE 6**. Vertical root fracture (38.4%) and progressive periodontal disease (38.4%) were the major causes of extraction, whereas persistent endodontic infection necessitated extraction of only 10 (0.9%) teeth (4 lower incisors, 2 lower and 1 upper molars, 2 upper and 1 lower premolars).

Life table analysis showed that the probability of tooth survival 20 years after endodontic treatment was 86% (**TABLE 7**).

The results of the Cox regression models are presented in **TABLE 8**. Preoperative radiolucency did not influence tooth survival. The multilevel model adjusted for the majority of factors that might influence survival of endodontically treated/re-treated teeth indicated that teeth that were treated in two appointments (medication appointment) presented reduced chances of survival as compared to teeth treated in a single sitting (no medication) (HR [hazard ratio] 1.80, P = 0.027). In terms of type of teeth, canines (HR 0.34, P = 0.002) and premolars (HR 0.51, P = 0.015) appeared to have better chances of survival than incisors (**TABLE 8**). Teeth treated for the first time for endodontic reasons had a better chance of survival than teeth treated for prosthetic or periodontal reasons (HR 2.05, P = 0.012) Re-treated teeth exhibited better survival than teeth treated for the first time (P = 0.024). Analyses were adjusted for age, as the increase in the age of patients reduced the chances of survival (HR 1.03, P = 0.006).

DISCUSSION

The results of this ambispective cohort study show that root canal therapy can provide good survival rates over a 20-year period, even in a high-risk population with multiple tooth/site risk factors. Indeed, in our sample the majority of treated teeth were affected by severe bone loss and/or poor residual sound structure at baseline, and 971 (83.1%) teeth were used as abutments in prosthetic rehabilitations. Even in a sample as problematic as this, only 151 (19.4%) of the endodontically treated teeth had to be extracted, and in only 10

TABLE 6 REASONS FOR TOOTH EXTRACTION: A) SUMMARY STATISTICS; B) DISTRIBUTION BY YEARS

a) Summary statistics of failure reasons for all teeth and for retreated teeth only

Reason	n = 151 (12.9%)	Re-treated teeth only n = 50
Periodontitis	58 (38.4)	14
Vertical tooth fracture	58 (38.4)	21
Caries	15 (9.9)	7
Endodontic	10 (6.6)	3
Replaced by implants*	4 (2.7)	2
Perforation	2 (1.3)	2
External root resorption	3 (2.0)	1
Strategic**	1 (0.7)	0

**These teeth were used as provisional abutments to support provisional prostheses, knowing in advance that they would be extracted*
***For subsequent prosthetic needs*

b) Reasons for tooth extraction

Year	Frequency	Percentage	Cause of failure
0	7	4.6	1 endo, 2 perio, 2 vertical root fractures, 1 replaced by implant, 1 perforation
1	13	8.6	2 endo, 7 perio, 1 vertical root fracture, 2 replaced by implants, 1 perforation
2	4	2.6	1 endo, 2 perio, 1 replaced by implant
3	4	2.6	3 perio, 1 external root resorption
4	8	5.3	2 endo, 2 perio, 3 vertical root fractures, 1 caries
5	3	2	1 endo, 1 perio, 1 caries
6	8	5.2	5 perio, 2 vertical root fractures, 1 caries
7	4	2.6	2 perio, 2 fractures
8	11	7.3	1 endo, 3 perio, 5 vertical root fractures, 1 caries, 1 external root resorption
9	7	4.6	2 perio, 5 vertical root fracture
11	18	11.9	8 perio, 6 vertical root fracture, 3 caries, 1 strategic
12	6	4	1 perio, 3 vertical root fracture, 2 caries
13	2	1.3	1 vertical root fracture, 1 caries
14	7	4.6	5 perio, 2 vertical root fractures
15	9	6	2 endo, 3 perio, 2 vertical root fractures, 2 caries
16	9	6	2 perio, 7 vertical root fractures
17	4	2.6	3 vertical root fractures, 1 caries
18	17	11.3	7 perio, 8 vertical root fractures, 1 caries, 1 external root resorption
19	10	6.6	4 perio, 5 vertical root fractures, 1 caries

teeth (0.9 %) the cause of failure was endodontic in nature. This data confirms the long-term reliability of natural teeth, even if seriously compromised. Considering the significantly higher risk of failure of implants placed in patients with a history of periodontal disease, it might be preferable to adopt a strategy with a better prognosis in terms of survival and complication rate[15-18].

TABLE 7 LIFE TABLE ANALYSIS OF TOOTH SURVIVAL 20 YEARS AFTER TREATMENT. EIGHTY-SIX PERCENT OF THE ENDODONTICALLY TREATED TEETH SURVIVED AT THE END OF THE 20-YEAR FOLLOW-UP

Interval	Number entering Interval	Number terminal events	Number withdrawing	Cumulative proportion surviving at the end of interval
0 1	1169	7	36	0.99
1 2	1126	13	42	0.99
2 3	1071	4	19	0.99
3 4	1048	4	22	0.98
4 5	1022	8	20	0.98
5 6	994	3	22	0.97
6 7	969	8	19	0.97
7 8	942	4	12	0.96
8 9	926	11	25	0.95
9 10	890	7	7	0.95
10 11	876	0	9	0.95
11 12	867	18	27	0.93
12 13	822	6	19	0.92
13 14	797	2	23	0.92
14 15	772	7	18	0.91
15 16	747	9	10	0.90
16 17	728	9	7	0.89
17 18	712	4	42	0.89
18 19	666	17	9	0.87
19 20	640	10	0	0.86

Comparing the 10-year with the 20-year follow-up, 15 teeth which had shown periapical lesion reduction and 5 teeth which had shown no changes at 10 years exhibited no pathological sign at 20 years. However, 61 teeth which did not display any pathological sign at 10 years exhibited worse radiographic signs at 20 years, while 21 teeth did not change between the two follow-ups. When the 20-year follow-up images were compared to the pre-operative radiographs, 91 teeth (12.6%) displayed no reduction in periradicular radiolucency, even if asymptomatic and fully functioning.

This finding is in contrast with that reported for another study, in which late periapical improvements with more successful cases were observed between the 10-17-year and 20-27-year follow-ups[19]. That being said, all our radiographic findings must be interpreted with caution, considering the difficulty in standardizing radiographs over a 20-year follow-up period. In addition, 2D analysis might not be a fully reliable radiographic healing assessment method, as the overlapping of multiple anatomical structures might hamper the detection of radiolucencies, particularly in the upper molars[20].

Despite these limitations, and in line with the protocols adopted by previous investigations with long-term follow-ups[21,22], 2D images were used for diagnostic purposes, since they were the most reliable tool at the time of treatment. This also allowed comparison with the pre-

TABLE 8 RESULTS OF COX PROPORTIONAL HAZARDS MODEL FITTED FOR THE SURVIVAL TIME TO FAILURE AND PATIENT'S AGE, TYPE OF TREATMENT (TREATMENT *VS.* RE-TREATMENT), PREOPERATIVE RADIOLUCENCY (PRESENCE *VS.* ABSENCE), ENDODONTIC TECHNIQUE (SCHILDER *VS.* CROWN-DOWN/LATERAL CONDENSATION), MEDICATION (PRESENCE *VS.* ABSENCE), TYPE OF TOOTH (INCISORS, CANINES, PREMOLARS, MOLARS, WISDOM TEETH), INITIAL REASON FOR TREATMENT (ENDODONTIC *VS.* NOT ENDODONTIC), AND PRESENCE OF SYMPTOMS FOR RETREATED TEETH (SYMPTOMATIC *VS.* ASYMPTOMATIC)

Explanatory variable	Hazard Ratio	Robust SE	P-value	95% CI
Age	1.03[a]	0.01	0.006	1.01 to 1.05
Re-treatment *vs.* treatment	0.53[b]	0.15	0.024	0.31 to 0.92
Radiolucency (presence *vs.* absence)	1.75	0.61	0.112	0.88 to 3.47
Medication (presence *vs.* absence)	1.80[c]	0.48	0.027	1.07 to 3.04
Technique (Schilder *vs.* crown-down)	0.780	0.23	0.451	0.46 to 1.41
Type of tooth				
- Canines *vs.* incisors	0.34[d]	0.12	0.002	0.17 to 0.68
- Premolars *vs.* incisors	0.51[e]	0.14	0.015	0.29 to 0.88
- Molars *vs.* incisors	0.92	0.24	0.776	0.55 to 1.54
- Wisdom Teeth *vs.* incisors	0.96	0.44	0.935	0.39 to 2.34
Reason for treatment	2.05[f]	0.91	0.012	1.23 to 5.10
Presence of symptoms	1.06	0.34	0.18	0.57 to 1.97

[a]*Increased patient's age reduces the chances of survival*
[b]*Re-treated teeth had better survival than treated teeth*
[c]*Teeth with intermediate medication presented reduced chances of survival*
[d, e]*Canines and premolars have better chances of survival than incisors*
[f]*Teeth treated only for endodontic reasons have better chances of survival than teeth treated for other reasons*

vious 10-year follow-up research (7). Moreover, current indications for the use of CBCT focus on patient safety[23], and it may be questionable to perform CBCT examination only for scientific purposes, without significant clinical benefit to the patient.

In the failure analysis, out of the 151 failed teeth, only 6.6% (10 teeth) were extracted due to persistent endodontic infection, whereas the great majority of extractions were caused by vertical root fractures (38.4%, 58 teeth) or periodontal disease progression (38.4%, 58 teeth). This is in line with a report by Di Febo et al., who found vertical root fracture and periodontitis progression to be the most prevalent failures in a high-risk population with multiple tooth/site risk factors, with frequencies of 48% and 31%, respectively, at 20-year follow-up[4].

Distribution analysis of failures revealed that multiple failures were concentrated in just a few patients. According to Salvi et al.[24], long-term tooth survival might be related more to patient risk factors (susceptibility to disease, smoking, bacterial plaque control) rather than to the tooth/site risk factors; this might explain the failure concentration in the few patients observed after our 20 years of follow-up. Unfortunately, however, we did not record the smoking habits of the patients before endodontic treatment.

In addition, the substantial incidence of vertical root fractures in our sample might be explained by the high number of root-resected teeth used as long-span bridge abutments. It is also interesting to observe that most of the few failures caused by the persistence of the endodontic infection occurred during the first 3 years after treatment.

When comparing the probability of tooth survival for teeth endodontically treated for the first time with teeth endodontically re-treated, after adjusting for other variables using the Cox proportional hazards model, the difference was statistically significant (P-value = 0.024). In other words, re-treated teeth had better chances of survival than teeth treated for the first time. This finding is in disagreement with reports by Sjögren[25] and Imura[26], but we find no reasonable explanation for this unexpected finding.

A statistically significant difference was found when comparing teeth treated in one session with those treated in two sessions with intermediate medication. Teeth treated for the first time in two sessions seemed to have a poorer outcome (P-value = 0.045). This finding might be explained by the use of the intermediate medication limited to canals with persistent exudation, symptomatic teeth, and teeth with periradicular radiolucency.

A statistically significant difference was also found when comparing different tooth types. Incisors were less likely to survive than canines (P-value = 0.00) and premolars (P-value = 0.029). This finding, once again, can be explained by the characteristics of the sample (progressive periodontal disease and fragility of the abutments). Endodontic failures were not associated with multirooted teeth, and this finding is in agreement with some studies[27] but not with others[6].

All complications that required tooth extraction were counted as complete failures, while 40 teeth (3.4%) experienced 41 complications that were successfully retreated. As regards the prevalence of complications, similar rates were reported for two large cohorts of insured dental patients treated by private dentists (109.452 and 44.613 patients respectively) followed up for an average of 22 months[28] and 3.5 years[29], respectively. These results suggest that the incidence of complications in endodontic therapy is low. The majority (2.6%) can be successfully treated, whereas in very few cases the affected teeth may require extraction (0.9%)[30].

Among the main limitations of the present study, the following should be considered: its partial retrospective design, the unknown clinical outcome of the 31.1% (128) of patients who dropped out, and the absence of radiographs for 15 teeth (1.3% of the sample). Ideally, the study should have begun as a prospective cohort study with a specifically designed protocol. However, no research protocol was conceived before the initiation of root canal treatments. That being said, data were recorded quite rigorously, and were systematically recorded in a prospective manner from 2007. A drop-out rate of about 31.1% (128 patients) of the treated patients over a 20-year period is acceptable, particularly when compared with the 70-73% drop-out rates after 4 to 6 years[27] or 54% after 8 to 10 years[25] reported for other studies.

When comparing the methodology of the present study with those previously published, the following observations can be made: in studies reporting 8-year[28] to 10-year[31] follow-ups, the actual mean observation time was unknown[28], though significantly shorter, or less than 3 years[31]. Other studies did not consider the teeth clustering effect in the same patient[6,26-29,31,32], and the great majority of similar studies did not give information on who performed the assessment, or on the number of and reasons for drop-out, with very few exceptions[25].

The survival rate reported in the present study (86%) is lower than the 92% reported as average in a systematic review[33] which included survival rates of four studies with a follow-up of 6 years or more. On the other hand, in two studies with about 10 years of follow-up, 10.7%[25] and 15.3%[6] of teeth were extracted. The most likely explanation for this difference could be the duration of the present study and the different patient sample.

The results of the present study could be generalizable to a wider patient population, bearing in mind that treatments were delivered by a single operator in a private practice mostly dedicated to endodontic therapy with a well-organized recall and maintenance system. It would be interesting to follow this cohort of patients for another decade to acquire even more information on the long-term prognosis of endodontic therapy.

CONCLUSIONS

The 20-year prognosis of endodontically treated/re-treated teeth as part of multidisciplinary rehabilitation of patients affected by advanced periodontitis is good. Twenty years after endodontic therapy, clinical survival rate was 86%, with 12.9% of teeth being extracted, only 0.9% for endodontic reasons, and 2.6% of teeth affected by successfully treated complications.

Aging, endodontic treatment in two sessions, and endodontic treatment for non-endodontic reasons are important predictors of failure, while preoperative radiolucency and endodontic re-treatment seem not to be. Root canal therapy can be considered a successful treatment long-term, even for teeth with multiple risk factors or those used as abutments for perio-prosthetic rehabilitations.

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