A retrospective comparison of the effectiveness of three methods of endodontic therapy of non-vital teeth

Abstract

The endodontic treatment of 1,720 non-vital anterior teeth and premolars was observed in the author’s general practice during 1985–1999 until December 2005. The analysis included success or failure and survival after non-surgical root canal treatment, root end resection or trephination with regard to various criteria. The failure analysis distinguished between clinical failures (acute exacerbations) that occurred within the first nine months of treatment only and failures with a follow-up radiograph. Operator, sex and age of patient, number of appointments, or initial or second treatment did not have a significant impact statistically. Regarding the results, the degree of root canal filling was of minor importance, only found to be of statistical significance regarding the development of an acute exacerbation after overfilling of conservatively treated teeth. Statistically significant factors were apical periodontitis before endodontic treatment, the homogeneity of a root canal filling and the restoration type. Posts were found to impair the treatment results. An increased extraction rate was observed among the patients in the lowest socio-economic group compared with those in the higher socio-economic groups. Ten years post-endodontic treatment, 15.6% of the conservatively treated teeth, 23.8% of the cases treated with root end resection and 23.7% of the trephination cases were available for analysis without preceding re-intervention.

Introduction

Primarily conservative therapy is recommended for therapy of non-vital teeth, as the endodontic literature reports a high success rate. Another therapy is root end resection (RER); however, this indication has been limited in the course of time. In connection with apical periodontitis (AP), root canal filling (RCF) is performed before or during treatment with or without retrograde RCF. During the last 15 years, RER studies have only dealt with RER in connection with retrograde RCF. However, RER guidelines emphasise that an RER is not an alternative to an exact RCF and it is regretted that there are no epidemiological studies on RER, although, based on accounting data from health insurance providers in western Germany, payments for RER increased nearly threefold from 1984 to 2011. Payments for Schröder aeration (synonyms: apical aeration, artificial fistulation, trephination [TR]), a possible alternative therapy for conservative non-surgical root canal treatment (nsRCT) and RER,
have more than halved. Based on a scientific report, the prognosis of success for nsRCT is as follows:

- Vital extirpation and pulp necrosis of teeth without associated AP: 85–95%.
- Retreatment or revision treatment (RV) of teeth without AP: 89–95%.
- Pulp necrosis of teeth with AP: 70–85%.
- RV of teeth with associated AP: 50–70%.

The definition of success is essential for evaluating the success of treatment. This is defined based on the radiographic and the clinical findings (pain, fistula, swelling), and possibly on the examined teeth remaining in asymptomatic function regardless of the radiographic findings. A benchmark regarding strict or loose criteria is determined radiographically. Strict criteria imply complete AP healing, whereas classification according to loose criteria means that the reduction of AP is sufficient for confirmation of success. Ng et al.5 evaluated individual factors for success and classified these into strict or loose criteria; for example, regarding vitality before RCT: a vital success rate of 82.5% and 89.6%, respectively; and a non-vital success rate of 73.1% and 84.7%, respectively; or regarding evaluation of the technical quality of an RCF: a homogeneous success rate of 82.9% and 87.0%, respectively; and an inhomogeneous success rate of 61.1% and 64.2%, respectively. Using insurance data, Lazarski et al.6 checked the data of 110,000 insurants over an average observation time of 22 months. A negative incident (extraction [EX], RER, RV) occurred after an average of 14.7 months. During this time, 3.56% of the teeth treated with RCF were extracted, 1.84% underwent RV and 1.00% underwent RER.

Chen et al.7 looked at more than 1.5 million nonsurgical endodontic treatments covering a period of five years. During this time, 6.70% of the teeth were extracted, 0.29% underwent RER and 3.20% underwent RV. After five years, the survival rate for anterior teeth was 95.4% and 93.6% for premolars. The EX rate remained constant with 20% p.a., and 81% of all RERs and 40% of all RVs were performed in the first year post-RCT. During a ten-year observation period in Lumley et al.,4 74% of all teeth that had undergone RCF remained without re-intervention (EX, RER, RV). After one year, the percentage of teeth without re-intervention was 96%; after five years, it was 84%. Of those that failed 70% ended up in EX. The central incisors and the first premolars had the longest survival time; the lateral incisors and the canines the shortest. Salehri and Rotstein8 evaluated 4,744 cases of nonsurgical RV. During a five-year observation period post-RCT, 11.0% were extracted and 5.2% underwent RER.

Ng et al.10 evaluated survival rate based on 14 studies. The observation time ranged from one to 11.5 years, and 74–85% of the teeth treated with RCF survived to the end of observation time without re-intervention. In their review of 63 studies published between 1922 and 2002, Ng et al.11 found a success rate in the studies of 31–96% (a pooled and weighted rate of 74.7%) according to strict criteria and of 60–100% (a pooled and weighted rate of 85.2%) according to loose criteria. In the same study, they analysed the practitioner’s influence on the treatment result differentiated according to strict and loose criteria. General practitioners achieved a success rate of 65.7–86.2%, postgraduate students 77.2–93.1%, and specialists 84.8–87.6%.

Cross-sectional studies and epidemiological studies permit a survey of the quality of practitioners’ endodontic treatment results. Eriksen12 compared the success and failure of 14 clinical studies—with RCT by specialists and supervised students—and 28 epidemiological studies—with RCT by general practitioners. The success rate of the clinical studies varied from 77 to 94% (average: 86% were successful, 6% were uncertain and 8% failed) and of the epidemiological studies from 35 to 78% (average: 63% were successful and 37% failed).

Friedman13 consolidated data from 39 cross-sectional studies performed between 1976 and 2006. The rate of AP was 20–65%. RCFs were found to be inadequate in 48–87%. Alley et al.14 found a five-year survival rate of 89.7% for endodontically treated teeth for cases treated by general practitioners and of 98.1% by endodontists.

The figures mentioned prove that there is a discrepancy between learning and success in practice. Hülsmann and Snezna15 conclude that an optimal success rate cannot be achieved under practice con-

Fig. 2. Success with respect to the total failure rate by therapy type. The initial Diagnosis 1, 2 (n = 757) showed 6.1% (n = 46) flare-ups, the initial Diagnosis 3, 4, 5 (n = 963) 4.3% (n = 41) flare-ups thus influencing the total failure rate.
In 1973, 1983, 1993 and 2003, Frisk et al. examined 500 patients each in order to determine possible developments in endodontic performance. Over the years, RCF quantity and quality, especially in molars, increased. In contrast, RER quantity remained significantly unchanged statistically (21.1–24.8 %).

Skudutyte-Rysstad and Eriksen observed the endodontic status of 35-year-old patients from Oslo in Norway over three decades. In 1973, 18% (n = 100) of the examined RCF teeth exhibited AP; in 1984, 26% (n = 133); in 1993, 38% (n = 42); and in 2003, 43% (n = 61). From 1984 to 2003, the percentage of adequate RCF lengths increased from 41% to 61%, whereas RCF quality (homogeneity) remained unchanged. Frisk and Hakeberg arrived at different results in evaluating women’s dental status in 1968, 1980 and 1992. AP rate in endodontically treated teeth remained at a level of 41.9% from 1968 to 1980, and decreased to 31.1% from 1980 to 1992.

Eckerbom et al. observed an increase in RCTs from 13.9% to 17.7% within 20 years. Although RCF quality improved significantly, the diagnosis of AP in teeth that had undergone RCT increased from 17.3% to 21.4%, and 28.8% of the teeth had to be extracted.

In 1984, 5,148,000 canal preparations were performed in western Germany, and 7,882,000 in 2011, an increase of 53.1%. RCF procedures amounted to 4,287,000 in 1984 and to 6,195,000 in 2011, an increase of 44.5%. This shows that 83.3% of prepared canals were filled in 1984 versus 78.6% in 2011.

The results of the various studies led Torabinejad et al. to remark as follows: “The older endodontic literature recorded the highest overall quality rating and included the most high-level studies. Changes in treatment that have occurred over time may have introduced biases favouring the discipline with the most recent papers.”

Hepworth and Friedman stated in 1997 that the majority of the RER studies do not reflect current RER techniques, which are used in the prospective Toronto study. According to this study, 74% of 134 RER cases could be judged as healed and 94% were indicated as “functional.” In the case of an inadequate RCF level (underfilling or overfilling), the healing result of 84% was more favourable than that of 68% with proper RCF levels. A tabular survey of 12 studies performed in 1968–1991 by simultaneous RCF and RER without post-RCF showed a healing rate of between 55% and 90% (average: 81% were successful and 7% failed), and another table of 22 RER studies performed in 1968–1995 with RER and retrograde RCF showed a healing rate of between 43% and 89% (average: 59% were successful and 19% failed).

Friedman found that a combination of orthograde RCF and RER had a better prognosis of success than did a combined RER and retrograde RCF; however, he mentions this for academic interest only because of the high success of the current RER methods. Essentially, alternative therapies have to be considered for saving a tooth, one of which should be RER.

Rud et al. compared the treatment results of 763 cases of orthograde gutta-percha RCF with 237 cases of RER and retrograde amalgam RCF. After one to ten years, the following radiographic findings were made: 83% complete healing, 8% incomplete healing, 6% indeterminate findings and 3% failed after orthograde RCF; compared with 72% complete healing, 11% incomplete healing, 8% indeterminate findings and 9% failed after RER and retrograde RCF.

Grung et al. compared the treatment outcomes of 397 cases of RER with 76 cases of periapical curettage after an average of 2.3 years. Complete healing of 78.3% was achieved with RER versus 78.9% with curettage. In order to obtain a failure rate, the authors listed unsatisfying and uncertain healing in the failure group. These failures amounted to 13.3% after RER and to 5.2% after curettage, while those after orthograde RCF (312 of 477) were lower (4.9%) than those after RER and retrograde RCF (27.9%).

<table>
<thead>
<tr>
<th>Therapy</th>
<th>n</th>
<th>%</th>
<th>n</th>
<th>%</th>
<th>Years</th>
<th>Years</th>
<th>n</th>
<th>%</th>
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<td>234</td>
<td>51.6</td>
<td>322</td>
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<td>6.08</td>
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<td>322</td>
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<td>57.4</td>
<td>5.27</td>
<td>5.02</td>
<td>353</td>
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<td>TR</td>
<td>743</td>
<td>359</td>
<td>48.3</td>
<td>435</td>
<td>58.8</td>
<td>5.97</td>
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</tr>
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<td>TOTAL</td>
<td>1,720</td>
<td>880</td>
<td>51.2</td>
<td>1,058</td>
<td>61.5</td>
<td>5.59</td>
<td>5.90</td>
<td>1,162</td>
</tr>
</tbody>
</table>

Table 1 - Cases of non-vital teeth in relation to sex, operator, and average observation period and time to follow-up radiograph.
According to Friedman and Mor, the results of 57 RER studies between 1966 and 2004 are not consistent. The authors found complete healing of between 37% and 85% in these studies. It could be concluded that 86–92% would remain asymptomatic.

Kirchen evaluated 185 RER cases, treated from 1983 to 1995. Pre-RER, 45% were diagnosed with AP. Of the cases, 171 were filled with N2 or gutta-percha. A clinical check-up was done after an average of 5.6 years. A radiographic check-up was performed after an average of 6.2 years. Complete healing was observed in 154 cases (83.2%), scar formation in eleven cases, incomplete healing in 15 cases, and uncertain healing in three cases. Only two cases were regarded as failures. Nine teeth were extracted after an average of six years.

To a large extent, the literature accepts TR as an emergency measure only. However, studies do exist that systematically used TR as the final step of RCT of non-vital teeth. Sargenti has called RER obsolete and recommended replacing RER with TR. He states that TR is a therapy alternative equal to RER for endodontic treatment of non-vital teeth, whereas nsRCT should be regarded as a less successful method.

_Materials and methods_

The author, who started as a dental practitioner in 1969, used the 1,790 endodontic treatment cases of non-vital anterior teeth and premolars registered in his patient files from 1985 to 1999. Of these, 70 cases (3.9%) had not returned to the practice after RCT. Thus, 1,720 cases remained for analysis. Of these, 743 teeth had been treated by RER, 453 by TR and 524 by nsRCT. The observation period ended in December 2005. The patients came to the practice on their own accord without intentional recall.

All of the teeth were treated with a simplified endodontic technique following Sargenti’s N2 method, which included relative drying, manual canal preparation with reamers in the crown-down technique, optional radiographic measuring, no canal rinsing, lentulo application of N2 RCF material (paraformaldehyde component in powder, allowing a gaseous canal disinfection), and gutta-percha point concentration of RCF. The target was RCF to the apex. Normally, overfilling was followed by TR or RER. Periapical curettage was only performed in the case of massive overfilling. TR and RER were done in the premolar area by flap (angle or trapeze cut). A cross-cut

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was chosen for the anterior tooth area in the initial years (one tooth width for TR and three tooth widths for RER). In later years, the cross-cut was replaced by a flap. After opening and bone exposure in the periapical area, the bone was penetrated with an elongated turbine bur (# H 1-018, Komet) and occasionally with a bud bur and handpiece with water-cooling from the unit. If curettage or RER was planned, the bur opening was enlarged and, in the case of RER, the root tip was cut to a flat bevel of approximately 3 mm.

Radiographic diagnosis before RCT was performed according to five criteria:

1. apex without pathological findings
2. apex likely without pathological findings and with periodontal gap enlargement
3. AP of < 25 mm
4. AP of 25–50 mm
5. AP of > 50 mm.

The AP dimension was measured as follows: the longest AP dimension parallel to the tooth axis multiplied by the largest dimension vertical to this. The follow-up radiographs (Radiograph 3), single-tooth radiographs only, were evaluated according to three criteria:

1. apex without pathological findings and AP completely healed
2. apex not determinable, AP incompletely healed, suspicion of scar, and periodontal gap enlargement
3. failure: AP unchanged, enlarged, newly developed.

Radiographs were evaluated in cases in which RCT dated back one year or more. The radiographs were viewed and evaluated by three independent experts independently: Prof. J. Klammt (oral surgeon), Dr E. Goffart (30 years of experience, frequently acts as a forensic dental expert) and the author himself (40 years of experience). A 2× and a 7× magnifier with a 0.1 mm scale were used.

The two independent experts had never worked according to the N2 method. The majority opinion was applied for definite radiographic diagnosis. In the case of three different opinions, the mean diagnosis was chosen. Failures with an accompanying radiograph were indicated as Failure 2 and clinical failures (pain, swelling, fistula) without a follow-up radiograph as Failure 1, which mostly resulted in re-interventions (EX, RER, RV, TR).

Regarding radiographic diagnosis, the level of agreement between the experts was determined according to Cohen’s kappa. A high level of agreement was achieved, with the following kappa values: 0.74 for Prof. Klammt, 0.73 for Dr Goffart and 0.63 for the author.

Independent of the existence or diagnosis of a follow-up radiograph, survival rates were calculated using various target criteria. As the terminal point of survival, the date of the last appointment in the practice without previous re-intervention was added to DP. Thereafter, the new survival cycle ended after the results of a re-intervention. The failure rate calculations were based on those 1,720 cases that returned to the practice after RCT with or without follow-up Radiograph. Failure 1 rate concerning acute exacerbations related to the total of 1,720 cases, and Failure 2 rate to cases with follow-up Radiograph.

The data was entered into the SPSS statistical software package (Version 10.0; SPSS) and the survival probability was calculated according to the Kaplan–Meier method. An error probability of < 0.05 between the examined parameters was determined as being statistically relevant.

**Results**

The male sex accounted for 880 of the 1,720 cases analysed (51.2%) and for 37 of the 87 acute exacerbations (42.5%). The difference between the male and

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**Table 2** Follow-up radiographic diagnosis and Failure 2 rate in relation to the presence of initial AP.

<table>
<thead>
<tr>
<th></th>
<th>Follow-up radiographic diagnosis</th>
<th>Failure 2 rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>AP: no</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NsRCT</td>
<td>205</td>
<td>81.5</td>
</tr>
<tr>
<td>RER</td>
<td>130</td>
<td>83.1</td>
</tr>
<tr>
<td>TR</td>
<td>165</td>
<td>88.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>500</td>
<td>84.0</td>
</tr>
<tr>
<td>AP: yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NsRCT</td>
<td>148</td>
<td>60.8</td>
</tr>
<tr>
<td>RER</td>
<td>357</td>
<td>73.9</td>
</tr>
<tr>
<td>TR</td>
<td>157</td>
<td>76.4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>662</td>
<td>71.6</td>
</tr>
</tbody>
</table>
female sexes approached significance regarding acute exacerbations ($p = 0.075$). Of the 149 Failure 2 cases, 89 (59.7%) were attributed to the male sex and 60 (40.3%) to the female sex. The difference was not statistically significant.

**Table 1**

No statistically significant differences in failure rate were found between operators (author vs assistant doctor), or for number of appointments (1 vs > 1; 40.5% of cases had > 1 appointment), age (< 30; 30–50; > 50), or primary vs secondary RCT (20.8%). The EX data indicated a statistically significant difference ($p = 0.029$) related to therapy type. After five (ten; 15) years, 88.9% (72.2%; 57.1%) of nsRCT cases, 88.7% (76.8%; 69.9%) of RER cases and 90.5% (80.6%; 70.6%) of TR cases had survived without EX. The highest EX rate was observed for maxillary premolars (20.6%) and the lowest for maxillary anterior teeth (12.3%), and 36.0% of EX were due to a non-re-storable natural crown (caries or fracture), 26.4% due to periodontal disease and 30.2% due to endodontic failure. Social stratification was noted in connection with EX. The lowest socio-economic group was represented by 59.2% of the patients and EX amounted to 65.5% in this group. Higher socio-economic groups, such as employees and private patients, were represented by 28.8% and 10.7%, respectively, and EX was 24.8% and 9.7%, respectively.

nsRCT showed the most acute exacerbations (Failure 1) compared with RER and TR, indicating statistical significance ($p = 0.029$). The development of Failure 2 was independent from pain anamnesis.

**Table 2**

Depending on the initial diagnosis of no AP (Diagnosis 1 or 2) or with AP (Diagnosis 3, 4 or 5), follow-up radiographic diagnosis and Failure 2 rate were combined in Table 2. Before RCT, the teeth with AP were as follows: $n = 222$ (42.4%) for nsRCT, $n = 524$ (69.6%) for RER and $n = 217$ (47.9%) for TR. These AP teeth were evaluated radiographically as successful (follow-up radiographic Diagnosis 1) as follows: 60.8% of nsRCT cases, 73.9% of RER cases and 76.4% of TR cases. If the initial diagnosis was no AP, the results were better: 81.5% of nsRCT cases, 83.1% of RER cases and 88.5% of TR cases.

During the first four years after RCT, 38.0% of the follow-up radiographs were performed: 39.0% of nsRCT cases, 37.8% of RER cases and 37.6% of TR cases. Radiographically, the TR cases represented the highest success and lowest failure rates (81.1% and 9.3%). Furthermore, it was considered whether a radiographic Diagnosis 3 after a period of less than four years provided similar results to a diagnosis more than four years after RCT. The radiographs of the later period found a worse result regarding Diagnosis 3 (9.7% vs 13.4%) and Diagnosis 1 (79.3% vs 74.6%), whereas Diagnosis 2 remained nearly unchanged (11.0% vs 12.0%).

In the analysis of single-tooth positions, mandibular incisors were found to be the tooth group with the most frequent Diagnosis 3 (17 of 78 = 21.8%). The maxillary lateral incisors had the second most frequent Diagnosis 3 (34 of 215 = 15.8%). This tooth location showed a significantly shorter survival rate compared with all other locations regarding the criteria for Failures 1 and 2. The survival rates of the maxillary lateral incisors after ten years were as follows: 46.5% ($p = 0.001$) for those treated with RCT, 81.9% ($p = 0.027$) for RER and 87.8% ($p = 0.949$), i.e. not significant for TR. The mandibular premolars were most rarely given Diagnosis 3 (14 of 199 = 7.0%), followed by the maxillary central incisors (22 of 216 = 10.2%).

Follow-up radiographic Diagnosis 3 was not the only criterion for recording Failure 2. Failure 2 with an accompanying radiograph accounted for 138 cases proved by radiographic Diagnosis 3 and a further eleven cases (7.4% of the 149 failed cases), resulting in a radiographic Diagnosis 1 for nine and Diagnosis 2 for two. The diagnosis of six of the cases as having AP was found to be incorrect after EX. Four cases underwent RER. One case of pain remained without therapy. The 149 Failure 2 cases were allotted to the three therapy types as follows, with the percentage of follow-up radiographs: 44 (12.5%) to nsRCT, 70 (14.4%) to RER and 35 (10.9%) to TR. The Failure 2 rate decreased linearly until 216 months after RCT. The most common localisation for Failure 2 after RER and TR was in the
anterior mandible (19.4% and 15.2%, respectively). Leading in EX rate were the maxillary premolars with 20.6%, followed by the mandibular anterior teeth with 16.4%, the mandibular premolars with 15.8% and the maxillary anterior teeth with 12.3%.

The incidence of acute exacerbation affected the total failure rate. There were 87 acute exacerbations (Failure 1) — 70 (12.9%) after nsRCT, 4 (0.5%) after RER and 13 (2.9%) after TR — and 61 (70.0%) of these cases occurred within 14 days of RCT and the last after nine months. A statistically significant Failure 1 rate was observed after nsRCT overfilling ($p = 0.020$), but not after TR overfilling ($p = 0.477$). In 128 cases of nsRCT overfilling, 25 cases (19.5%) reacted with Failure 1, and this was observed for nine cases of 283 TR overfilling (3.2%). The Failure 2 rate was 14.4% after RER irrespective of the RCF level. An RCF level of 0 to –1 ended in a Failure 2 rate of 8.5% in nsRCT cases and 8.2% in TR cases. Furthermore, a Failure 2 rate was diagnosed as follows: 13.6% of nsRCT cases and 16.7% of TR cases after underfilling; 17.7% of nsRCT cases and 10.9% of TR cases after overfilling.

Table 3

Statistical significance depending on the RCF level could not be proven for Failure 2 for the three therapy types, although substantial underfilling (–5) and overfilling (+5) each led to a failure rate of 19% (8 of 42 and 25 of 131, respectively). Aggregation of Failures 1 and 2 showed a $p < 0.001$ for RER and TR, respectively, versus nsRCT.

Table 4

Similar to the failure rate, statistically significant differences regarding the survival rate after five, ten and 15 years based on the target criteria for Failures 1 and 2 were observed. The greatest survival rate after 15 years after an initial diagnosis of AP was in teeth treated with RER (76%). Teeth with an initial diagnosis of no AP and treated with TR had the greatest survival rate after 15 years (87.9%).

Table 5

The RCF quality (RCF-qu) of the material was checked in order to verify a possible influence on the failure rate. Based on this, 1,522 cases (88.5%) were allocated to category RCF-qu1 (good quality) and 198 cases RCF-qu2 (poor quality). The relative number of RCF-qu2 failures was twice as high as RCF-qu1 failures:

- RCF-qu1: 75 cases (4.9%) were considered Failure 1 and 117 cases (11.4%) were considered Failure 2 — no statistically significant difference.
- RCF-qu2: 12 cases (6.1%) were considered Failure 1 and 32 cases (23.9%) were considered Failure 2 — a highly statistically significant difference with $p < 0.001$.

A survival comparison showed a correspondingly large difference in survival rate ($p < 0.001$) between RCF-qu1 and RCF-qu2 based on the target criteria for Failures 1 and 2.

Table 6

The failure or lasting success of the various restoration types was demonstrated. The basis for the analysis was the 1,162 cases with a follow-up radiograph: 668 filled teeth (57.5%) with 93 teeth (13.9%) considered Failure 2. 305 teeth with a crown but no cast post (26.2%) with 18 teeth (5.9%) considered Failure 2, and 189 teeth with a crown and a cast post (16.3%) with 38 teeth (20.1%) considered Failure 2 (Fig. 4).

Comparison between filled teeth and teeth with a crown without a post found a highly statistically significant difference in survival rate with $p < 0.001$. This was $p = 0.001$ for comparison between teeth with a crown with a post and those without a post. No statistically significant difference in the survival rate between filled teeth and teeth with a crown with a post was found ($p = 0.507$).
The drop-out rate was determined by the following parameters characterising a re-intervention and the end of observation: 258 cases of EX, 65 cases of RER, 37 cases of TR, and 15 cases of RV—seven of which were in connection with RER and five with TR. The last appointment was relevant for patients who did not undergo re-intervention.

While EXs were distributed evenly over the observation period, the other factors determining drop-out accumulated in the first year post-RCT. The drop-out rate over the period and across the three therapies is shown in Table 7.

### Discussion

The present study has attempted to establish average success and survival rates based on the same patients. The analysed cases were collected from the author’s general practice. Therefore, under the same research and evaluation conditions, the results of cross-sectional studies as mirror images of endodontic work in other practices, as described in literature, may be expected from this success and survival analysis. The patients in these studies represent a cross-section of the population, including patients who are not conscientious about oral care, in contrast to longitudinal studies at clinics consisting of a positive patient pool owing to selection of patients who undergo...
Failures 1 and 2, depending on initial diagnosis and therapy.

Table 4. Survival rate in relation to failures 1 and 2, depending on initial diagnosis and therapy.

<table>
<thead>
<tr>
<th>Therapy</th>
<th>Years</th>
<th>Survival rate (%)</th>
<th>P-value</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Diagnosis 1, 2</td>
<td>Diagnosis 3, 4, 5</td>
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<tr>
<td>NsRCT</td>
<td>5</td>
<td>86.1</td>
<td>73.3</td>
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<td>10</td>
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<td>15</td>
<td>79.3</td>
<td>71.0</td>
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</table>

A problem was that the number of clinical cases (n = 1,720) outnumbered the cases with a follow-up radiograph (n = 1,162). Numerous endodontic studies do not define the end of RCT being the start of the analysis, but only with a temporal delay, so early failures or interventions are not considered in the analysis. Furthermore, cases without a follow-up radiograph and patients with health problems affecting the immune system (diabetes, HIV/AIDS, steroid therapy, chemotherapy) are excluded from evaluation. Moreover, failures are often only based on the evaluation of radiographs, on which apical rarefactions cannot always be visualised. The present study is based on 149 radiographs accompanying Failure 2 cases, of which in 11 cases (7.4%) the radiograph showed no AP. In a previous study by the author,\textsuperscript{39} on the EX of 1,160 endodontically treated teeth in his own practice, endodontic failure (n = 245) was the reason for EX. For n = 35 (14.3%), a failure was only discovered after EX. If the teeth without a follow-up radiograph were not considered in this study, the acute exacerbations, which occur anyway under the one-year limit and are decisive for the high failure rate of nRCT, would not appear as clinical failures and the failure rate would only be based on the radiographic findings. Thus, the clinical failures were related to all patients visiting the practice again after undergoing RCT. The file research in this study found 87 teeth deemed Failure 1 (5.1%), 70 of which had undergone nRCT (12.9%) of all nRCTs), 13 of which had undergone TR (2.9%) of all TRs) and only four of which had undergone RER (0.5%) of all RERS. Balaban et al.\textsuperscript{40} report a 10% incidence of acute exacerbation in 157 asymptomatic teeth with necrotic pulp with existing AP. Tsessis et al.\textsuperscript{41} found a range of acute exacerbations of 1.5–20.0%.

Recall in the author’s practice did not take place. An average observation period of 5.9 years for the 1,720 cases was achieved though, even if only 67.6% underwent a follow-up radiograph. Recall might have generated a higher patient appearance in observation. In their review of 63 studies, Ng et al.\textsuperscript{5} describe a recall rate of 52.7% and the lowest of 11.0%. After one year, Orstavik\textsuperscript{42} achieved a recall rate of 71%, decreasing to 33% after four years. The success rate in the remaining patients had increased. This raises the question of whether dissatisfaction with the treatment may have made patients stay away.\textsuperscript{43} The authors assume that the reason for the drop-out of the concerned patients was postoperative problems, pain up to failure. A further decrease of recall rate over the years with a simultaneous increase in success rate led Wu et al.\textsuperscript{43} to speculate that only patients satisfied with treatment might attend appointments, whereas patients with poor RCT results might stay away. According to Orstavik et al.,\textsuperscript{44} 18% of the patients never visited the dental practice again after RCT. In the present study, the percentage was 3.9%.

When following up their RER patients, Rud et al.\textsuperscript{24} realised that the percentage of cases with incomplete and uncertain healing decreased within the first postoperative years, whereas the percentage of successful treatments and failures increased. After more than four years, only insignificant changes were observed. Friedman report a relapse rate after RER of 5–42% after more than four years. Eckerbom et al.\textsuperscript{19} re-examined their RCT patients after 20 years and found that the AP rate in teeth that had undergone RCT had increased from 17.3% to 21.4%. The Deutsche Gesellschaft für Zahn-, Mund- und Kieferheilkunde [German society for dental and oral medicine]\textsuperscript{1} has warned that the endodontic success of long-term follow-up is being overestimated. The author’s analysis confirms a decrease in RCT success rates, as well as an increase in failure rates after four years.

The type of health insurance indicated no greater incidence of failures among individual patient groups. Regarding EX rate, a socio-economic component could not be ignored however. The lowest socio-economic group constituted 59.2% of the pa-
tient sample, but accounted for 65.5% of EX. The EX rate in the higher socio-economic groups was more favourable in relation to their percentage of the patient sample. Thus, the patient sample in this study confirms the finding in the literature\footnote{Ng et al.} that socio-economic status does influence loss of teeth: the lower the status, the sooner EX is performed.

According to Ng et al.\footnote{Ng et al.}, predictors of increased loss of teeth were preoperative pathology, tooth fracture and restoration with a post. The last had a 2.6 times greater EX rate. The authors found the highest EX rate (9.9%) after primary RCT in the maxillary premolars. In the course of a significantly longer follow-up period, the present study found the highest EX rate in the maxillary premolars (20.6%) and the lowest in the maxillary anterior teeth (12.3%).

With respect to primary and secondary RCT, statistically significant differences regarding development of Failure 2 and the number of EXs were not found. After five (ten) years, 93.1% (84.9%) did not exhibit Failure 2 after primary RCT, nor did 95.2% (87.1%) after secondary RCT. However, acute exacerbations after nsRCT developed more often after secondary RCT (17.6%; n = 21) than after primary RCT (12.1%; n = 49). Five (ten; 15) years after RCT, the EX survival rate was 88.9% (72.2%; 57.1%) after nsRCT, 88.7% (76.8%; 69.6%) after RER and 90.5% (80.6%; 70.6%) after TR. A comparison of nsRCT and TR showed a statistically significant difference of $p = 0.104$. No statistically significant difference was noted between nsRCT and RER ($p = 0.104$). After five years, the present study showed the same EX rate of 11% as Salehrabi and Rotstein.\footnote{Salehrabi and Rotstein.} Also Ng et al.\footnote{Ng et al.} noted no difference in EX rate between primary and secondary RCT after two to four years (4.6% and 4.8%, respectively). Pain and the insertion of a cast post led to a statistically significant loss of teeth. Overfilling had no effect in the first 22 months post-RCT, but did later on. In another study, Ng et al.\footnote{Ng et al.} found that flush RCFS and those that were too short in a primary RCT led to the same success rate provided that there was no AP pre-RCT. However, they attached special importance to RCF quality: a success rate of 82.9% with good quality RCF and of 61.1–64.2% with poor quality RCF. In the case of the Failure 1 rate, the present study did not show any difference with regard to RCF quality. The failure difference (development of Failure 2) between good and poor quality RCF was highly statistically significant ($p < 0.001$). The Failure 2 rate was more than double with poor quality RCF compared with good quality RCF.

Ten years after RCT, 87.6% of teeth with good quality RCF and 70.5% of teeth with poor quality RCF did not exhibit Failure 2. In the present study, relatively fewer teeth were extracted after overfilling versus underfilling and RCF of length 0 to –1.

The mandibular premolars featured the lowest Failure 2 rate (9.5%) and the mandibular incisors the highest (21.8%), followed by the maxillary lateral incisors (16.3%). The high Failure 2 rate for the mandibular incisors may be due to the fact that these teeth often have two canals and that the filling of a second canal might not have been registered. The Failure 2 rate was as follows for the maxillary lateral incisors: 17.9% for nsRCT, 18.9% for RER and 11.4% for TR. The higher Failure 2 rate for the maxillary lateral incisors might be attributed to the anatomic situation of the root tip pointing in the palatal direction and thus a more complicated diagnosis, as well as to the increased presence of a scar, especially after RER, as mentioned by Friedman\footnote{Friedman} and Kirchen.\footnote{Kirchen.} Kerekes\footnote{Kerekes} found that the lowest success rate for all tooth locations was for the maxillary lateral incisors: 43% after RCT by practitioners and 68% after RCT by students. Kerekes\footnote{Kerekes} specified a general success rate of 60% for practitioners and of 82% for students.

According to Ng et al.\footnote{Ng et al.}, predictors of increased pain are waiting might have led to pain re-exacerbation after primary RCT, nor did 95.2% (87.1%) after secondary RCT. However, acute exacerbations after nsRCT developed more often after secondary RCT ($p = 0.104$). After five (ten) years, 93.1% (84.9%) did not exhibit Failure 2. In the present study, relatively fewer teeth were extracted after overfilling versus underfilling and RCF of length 0 to –1.

It is important to note that TR as therapy for pain is judged in this study as success limiting. Possible follow-up therapies in acute exacerbations have not often been described in the endodontic literature. Perhaps, a wait-and-see attitude is often adopted and/or analgesics are administered. Instead of immediately reacting with a therapeutic measure (EX, RER, TR) in the case of pain, waiting might have led to pain re-exacerbation anyway, thus improving the mentioned RCT survival and failure results.

It is important to note that the number of remaining teeth was ultimately higher than might be assumed by the failure rate, as failure did not necessarily mean loss of teeth; 105 cases remained in situ after RER, TR or RV, starting a new survival cycle on the day of re-intervention.
Follow-up radiographs were evaluated one year or more post-RCT, based on the statement by Orstavik\textsuperscript{42} that the radiographic evaluation would make sense from this point, as 51\% of the preoperative lesions will have healed after one year in relation to 76\% of the lesions in teeth that were AP-free upon the start of treatment. Molven et al.\textsuperscript{48} proved that late periapical changes may even occur after ten years or longer, especially after overfilling. This corresponds to the histological findings of Malooley et al.\textsuperscript{49} that, in the case of well-condensed overfilling, only delayed healing occurs. The authors observed no histological healing in the case of underfilling and poor quality RCF.

According to Wood et al.,\textsuperscript{50} 45\% of all surgically treated AP heals within one to ten years, but 25\% will never heal completely. Grung et al.\textsuperscript{24} report the healing results (> 78.0\%) for RER and periapical curettage as identical; however, it has to be considered that the RER cases included RERs followed by RCF, lowering the RER healing result, with a failure rate of 27.9\% versus a failure rate of 4.9\% in RER cases with orthograde RCF. Friedman and Mor\textsuperscript{26} found a success rate of 37–91\% for RER in their survey with asymptomatic continuance in function of 86–92\%. After primary and secondary RCT with initial AP, the authors report a healing rate of 74–86\%, as well as a functional survival rate of 91–97\%. Barone et al.\textsuperscript{23} found healing of 84\% in RER cases in the age group of over 45 and of 68\% in the younger age group. The authors thus considered success in relation to age. Statistically significant differences regarding success or failure according to age could not be proven in this study.

In the present study, almost 70.0\% of the RER cases were diagnosed with AP at the start of treatment, as were 42.4\% of the nsRCT cases and 47.9\% of the TR cases. Almost 73.9\% of the RER cases (60.8\% of the nsRCT and 76.4\% of the TR cases) were considered AP-free or healed based on the follow-up radiograph, after an average of 5.9 years. However, it cannot be excluded that, owing to scar or RCF resorption from the root canal end, some cases were misdiagnosed as AP. Therefore, the indicated success rate is in the mid-range of that in the literature on RER: a weighted average healing rate of 70\% according to Friedman and Mor\textsuperscript{26} and 81\% according to Hepworth and Friedman.\textsuperscript{21} The success rate of each of the three therapy methods compared in this study was 10–20 percentage points higher when there was no initial AP.

Aside from the mentioned AP, RCF quality and the restoration type had a decisive significance for treatment success and survival. Kvist et al.\textsuperscript{51} report about 13\% of apical lesions in restorations without a post and about 16\% in those with a cast post. In the present study, there was a Failure 2 rate of 20.1\% in teeth that had received a crown and a post, of 5.9\% in teeth that had received a crown but no post, and of 13.9\% in teeth provided with a filling. The chi-squared test revealed a percentage difference of $p < 0.001$, indicating high statistical significance. It has to be noted that the cast post itself accounts for failure to a lesser extent than a technical deficit: via falsa, insufficient RCF (length, homogeneity) before post insertion, as well as preparation of the root canal to too great a depth and thus less remaining RCF.

One can learn from the results that an additional TR or RER should be taken into consideration for therapy of non-vital teeth after orthograde RCF in order to guarantee a better treatment result. Overfilling was often followed by acute exacerbation, which might have been treated prematurely in the author's practice. RER was followed by only 0.5\% acute exacerbations. RER was preferred in the case of existing AP and TR was preferred after overfilling. Failures with a follow-up radiograph were diagnosed more frequently after RER compared with the alternative therapies. However, the differences were not statistically significant, although the teeth treated by simultaneous RCF and RER showed by far the highest rate of apical lesions at the beginning of RCT.

Under the conditions at the author’s practice, RER and TR were found to be therapy options superior to nsRCT.\textsuperscript{22}