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

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Dear Reader,

_It may seem that today, at the start of the third millennium, we have already seen all major revolutions in endodontics, if not in dentistry altogether, with the new breakthroughs and discoveries only detailing the techniques and technologies already in existence. To produce and research a new idea, dental scholars today need to join efforts with engineers, physicists, biologists, geneticists and others; one example of a relatively recent successful collaboration is the development of an NiTi heat treatment and twisting technology, which began a new era in the manufacture of endodontic files._

But do revolutions and advancements actually raise the overall standard and quality of treatment or is rather the implementation of the gold standard of patient care, based on the established scientific principles and clinical protocols, in the daily work of every practitioner, and not necessarily anything costly (e.g. the use of conventional irrigants and sterile water in a specific sequence to chemically prepare the root canal system, minimise postoperative pain and prevent internal leakage)? This, unfortunately, is yet to be achieved, and it will require overcoming psychological barriers, quasi-scientific bias, and financial limitations.

Inasmuch as we attempt to remain objective in assessing our own work, there are limits to self-criticism, especially when there is literature today supporting almost any technique. It is impossible to over-emphasise the importance of pushing oneself out of one’s comfort zone, and full conference halls and hands-on courses are good proof that there are many clinicians who have already embarked on the path of continuous learning and training.

In an ideal situation, manufacturers should have sufficient time to develop, test and verify new technologies before approving a new product. In the past, there were research and development departments that collaborated with reputable scholars and practitioners for about a decade prior to finalising a prototype for clinical trials. However, now it seems that the planet is rotating faster—and the urge to introduce novel ideas has never been stronger. Consequently, the risk of failure is higher than ever. It is absolutely critical that all new developments be deeply rooted in quality research with strict statistical control for significance. This would be the only way to protect clinicians, and ultimately patients, from failure and malpractice.

At present, our task is to achieve this goal in our own daily work in the office and in our communication with colleagues around the world. Our work should be aimed at developing best practice guidelines for the community, which will need to be updated regularly at consensus meetings. Alongside other professional journals, specialist endodontic publications like roots will play an important role in updating the community.

At the end of the day, each and every effort by a scholar, manufacturer, practitioner or assistant should uncompromisingly be aimed at patients’ health. Endodontic treatment too should be conducted in the interest of the patient, whose immediate well-being and long-term health should be seen as the utmost priority above all personal and corporate ambition.

Yours faithfully,

Prof. Philippe Sleiman, DDS, MSc, DDSc
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Assistant Professor, Lebanese University dental school
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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. Thus, a survival difference among the three therapy types was only based on a different Failure 1 rate.

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. Thus, a survival difference among the three therapy types was only based on a different Failure 1 rate.

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,

Primary care 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,⁴ 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 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.,⁸ 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. Salehrai and Rotstein⁹ evaluated 4,744 cases of non-surgical 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-
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 quality and quantity, 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% 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% 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.

Grunge 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%).
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...
comparison of three methods of therapy

studies

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 2x and a 7x 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

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Follow-up radiographic diagnosis</th>
<th>Failure 2 rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Follow up</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>AP: no</td>
<td>205</td>
<td>167</td>
</tr>
<tr>
<td>NsRCT</td>
<td>130</td>
<td>108</td>
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<tr>
<td>RER</td>
<td>165</td>
<td>146</td>
</tr>
<tr>
<td>TR</td>
<td>500</td>
<td>421</td>
</tr>
<tr>
<td>TOTAL</td>
<td>148</td>
<td>90</td>
</tr>
<tr>
<td>AP: yes</td>
<td>357</td>
<td>264</td>
</tr>
<tr>
<td>NsRCT</td>
<td>157</td>
<td>120</td>
</tr>
<tr>
<td>RER</td>
<td>1362</td>
<td>474</td>
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</tbody>
</table>

| Table 2 Follow-up radiographic diagnosis and Failure 2 rate in relation to the presence of initial AP.
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 pre-molars (20.6%) and the lowest for maxillary anterior teeth (12.3%), and 36.0% of EX were due to a non-re-reaturable 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%).
studies _ comparison of three methods of therapy

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 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.

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.

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.

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.

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.

<table>
<thead>
<tr>
<th>RCF length</th>
<th>Survival rate TR (%)</th>
<th>Survival rate nsRCT (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 years</td>
<td>10 years</td>
<td>5 years</td>
</tr>
<tr>
<td>&lt;-1</td>
<td>94.0</td>
<td>81.1</td>
<td>81.2</td>
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<tr>
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<td>89.7</td>
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<td>&gt;0</td>
<td>90.8</td>
<td>82.9</td>
<td>72.2</td>
</tr>
</tbody>
</table>

Table 3

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

<table>
<thead>
<tr>
<th>Therapy</th>
<th>Years</th>
<th>Survival rate (%)</th>
<th>P-value</th>
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</thead>
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<tr>
<td></td>
<td></td>
<td>Diagnosis 1, 2</td>
<td>Diagnosis 3, 4, 5</td>
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<td>15</td>
<td>79.3</td>
<td>71.0</td>
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</tbody>
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Table 4. Survival rate in relation to Failures 1 and 2, depending on initial diagnosis and therapy.

regular dental check-ups. In cross-sectional studies, Eriksen found a success rate of 35–78% compared with that of clinical studies of 77–94%. Ng et al. observed a treatment success rate among general practitioners of 65.7–86.2%. Therefore, the results of the present study are in the mid-range with the following success rates: 60.8% for NsRCT, 73.9% for RER, and 76.4% for TR. These results cannot be compared with the results of cross-sectional studies, as clinical failures are not considered here. The results of cross-sectional, longitudinal and survival studies have to be separated. According to Ng et al., survival rates in relation to EXs are always higher than failure rates.

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 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 NsRCT, 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 nsRCT (12.9%) of all nsRCTs), 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. report a 10% incidence of acute exacerbation in 157 asymptomatic teeth with necrotic pulp with existing AP. Tsesis et al. 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. describe a recall rate of 52.7% and the lowest of 11.0%. After one year, Orstavik 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. 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. 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., 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. 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. 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] 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 that socio-economic status does influence loss of teeth: the lower the status, the sooner EX is performed.

According to 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%; 89.6%) after RER and 90.5% (80.6%; 70.6%) after TR. A comparison of nsRCT and TR showed a statistically significant difference between 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 and Kirchen. 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 specified a general success rate of 60% for practitioners and of 82% for students.

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Follow-up radiographs were evaluated one year or more post-RCT, based on the statement by Orstavik 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. 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. 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., 45% of all surgically treated AP heals within one to ten years, but 25% will never heal completely. Grung et al. 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 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. 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 and 81% according to Hepworth and Friedman. 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. 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 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.

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case report  root canal position and anatomy complications

Getting to the 00.00 point

Author_ Prof. Philippe Sleiman, Lebanon

**Case 1**

The first is a clinical case that in my experience posed rather a challenge. The patient was referred to my office suffering from paraesthesia of his lower lip on one side after a root canal treatment had been performed on his mandibular second molar.

**Anatomy and nature still teach us** on a daily basis. Root canal treatment, while it is becoming a routine procedure, surprises and sometimes bad cases still occur. In this article, I will present two unusual case reports from my own practice.

The preoperative radiograph (Fig. 1), which was sent by his dentist, showed a well-performed root canal treatment that did not explain the clinical manifestations, but looking closely at the apical part one could observe that the obturation material lay in proximity to the apex of the mandibular canal. Immediate retreatment was required. Unfortunately, the material that had been used was the plastic carrier Thermofil (DENTSPLY), and it was extending into the nerve, causing the inflammation, and the inflammation was causing pressure on the nerve. The Thermofil was removed from the canals—never an easy thing to do—using K3XF files (Sybron-Endo; Fig. 2) and without any solvent in order to avoid any more damage to the nerve in case of leakage. I set the Elements Adaptive Motor (Kerr Endodontics; Fig. 3) to K3XF mode, first using a 25.06 file in the softened part of the gutta-percha with the System B plugger. I was very careful not to push the carrier further inside the nerve and not to damage the plastic carrier and lose the grip. The second file used was the 25.04 K3XF to remove more gutta-percha and to liberate the carrier.

The instrument was used to hold the carrier and to remove it from the canal (Fig. 4). Once the Thermofil
had been removed and the exact working length had been determined using the Apex ID apex locator (Axis, SybronEndo, Fig. 5), the canals were shaped following the SM sequence in TF Adaptive mode to the working length, and I used the EndoVac irrigation system (SybronEndo, Fig. 6) with cold physiological saline in order to reduce the inflammation by cooling down the roots. All of the canals were irrigated with the cold saline for at least 20 minutes. The reason I used this technique was to immediately lower the inflammation inside the mandibular canal, which is not well innervated. Reducing the inflammation inside and around the nerve can take a while and I needed to lower it as soon as possible. The canals were kept empty with a cotton pellet inside the access cavity and a hermetic seal on top.

I asked immediately for a CT scan (i-CAT, Imaging Sciences International) to be taken in order to study the case. To my surprise, I found that the position of the mandibular canal was different from the contralateral one and that it was in contact with the apex of the second molar where the root canal treatment was performed (Fig. 7).

The patient was prescribed anti-inflammatories and kept under observation. Several days later, his lip was normal in function, but there was still some of loss of sensibility. Thirty days postoperatively, another CT scan was taken (Fig. 8) in order to check the inflammation inside the nerve itself, but during this time we continued to irrigate the canals with cold physiological saline at intervals of three days.

Until the patient reported the slow return of sensitivity, I decided to seal the canals, and it was for me the moment of truth, since I knew that I needed to seal the canals to the 00.00 point and place a small puff of sealer at the end too. Carefully adjusted master cones were placed inside the canals with a very tight tug back. The correct amount of sealer was applied in order to avoid any excess and gentle warm obturation was performed with the...
Elements Obturation Unit (SybronEndo). The integrity of the obturation was checked with a CBCT scan (Figs. 9 & 10).

Six months later, a conventional radiograph was performed (Fig. 11) in order to follow up on the case; the patient was doing very well with a completely functional and sensitive lip. The final radiograph showed a sealed root canal space and none of the sealer inside the mandibular canal remained.

The conclusion of this case is that we will never know the reason for such a difference in the position of the mandibular canal between the right and left of the mandible, and that we need to respect the 00.00 point of the length of the roots—nothing more and nothing less. And the most important conclusion is that nature and the human body have a truly amazing healing power once the cause of inflammation has been eliminated.

**Case 2**

In the second clinical case, the patient presented at the office with problems biting on his molar, with a fistula on the buccal side of his mandibular first molar. The preoperative radiograph showed an acceptable root canal treatment performed in accordance with recommendations (Fig. 12).

Studying the radiographs in detail, we could obviously see that something was not right in the apical area of the mesial canals. A closer look indicated some kind of pathology in the coronal part of the distal canal and possibly a cervical resorption or an internal resorption that might explain the fistula in this area.

Again K3XF files were used to retreat the case, with the proper irrigation technique using the EndoVac. A 50.04 file or the ML3 file in TF Adaptive mode was used to shape the last 3 mm of the canals. Adequate master cones were prepared with a very strong tug back placed 0.5 mm short of the working length. My choice was the Elements Obturation Unit in order to perform the sealing of the root canal system. The choice of the plugger was made, selecting the largest plugger to reach 5 mm from working length in each canal, in order to generate hydraulic pressure and to seal in 3-D during the down-pack or the first wave of obturation. Manual pluggers were also adjusted to reach 5 mm and 10 mm from the working length. Medium viscosity was chosen for the cartridge with a large opening and the extruder was set to two arrows or fast injection. The sealer was placed on the cones and inserted into all four canals, the first wave of condensation was performed in the canals one after another, and the manual plugger that reached 5 mm from working length was used thereafter in order to control the apical plug. Sealer was placed inside the canal, the preheated cartridge was inserted very slowly with no pressure applied on the needle, since it should reach 7 mm from the working length, 5 mm was injected into each canal, manual pluggers were used to condense this part and final filling of the root canal system was performed, also followed by hand plugging. The hydraulic force generated with this technique is sufficient to seal lateral and accessory canals and, of course, the resorption in the distal canal that appeared in the final postoperative radiograph (Fig. 13).

The root canal system has a very complex anatomy and this is not often apparent on radiographs. Performing a partial root canal treatment and placing one cone is not the gold standard in root canal treatment. Sealing the root canal system is the final step performed by the endodontist to complete the root canal treatment, but it should be concluded with a hermetic seal on top of it.
Rationale for the suggested use of fibre post segments in composite core build-ups for endodontically treated teeth

Authors_ Drs Leendert Boksman & Gary Glassman, Canada

The restoration of teeth utilising composites still presents a myriad of clinical challenges for the dental clinician. This is especially true for extensively broken down teeth and as well, those teeth which have been accessed endodontically. Fibre posts such as the quartz Macro-Lock Illusion X-RO post (Recherches Techniques Dentaires—RTD) UniCore Fiber post (Ultradent), and DT Light-Post (RTD) are now the posts of choice for a direct one appointment restoration of the severely compromised endodontically treated tooth. Current research supports the use of an etch and rinse bonding protocol, with a compatible bonding agent, utilising a dual-cured composite cement that can be utilised for the core as well (Cosmecore—Cosmedent; CoreCem—RTD; Zircules—Clinician’s Choice) for best results.\(^1,2\) Traditionally, minimally accessed endodontically treated teeth that are not extensively compromised by caries or fracture, have been restored solely with a composite core, without the placement of a post. This decision must be based on the amount of tooth structure left, and if a full coverage restoration is to be placed now or in the future. The width and height of the ferrule remaining is critical to restorative success (Figs. 1a & b),\(^3,4\) as well as the number of tooth walls left, post preparation, which significantly affects the long-term restorative outcome (Fig. 2).\(^5,6\)

In a review of 41 articles published between 1969 and 1999 (the majority from the 90s), Heling states that ‘the literature suggests that the prognosis of root canal-treated teeth can be improved by sealing the canal and minimising the leakage of oral fluids and bacteria into the peri-radicular areas as soon as possible after completion of root canal therapy.’\(^9\) A similar review by Saunders et al also concluded that coronal leakage of root canals is a major cause of root canal failure.\(^10\) Sritharan states that ‘it has been suggested that apical leakage may not be the most important factor leading to the failure of endodontic treatment—but that coronal leakage is far more likely to be the major determinant of clinical success or failure.’\(^11\) Coronal microleakage can occur due to a deficient final restoration (due to resultant microleakage from polymerisation contraction, cement wash out, poor full coverage, flex etc) and resultant secondary caries.\(^12\)
Polymerisation contraction (shrinkage)

Many different types of composites are now available to the practitioner including microfills, macrofills, hybrids, and small particle hybrids, nanofills, nanohybrids, or microhybrids. Even though the formulations can be adjusted in handling to make these composites ‘packable’, ‘flowable’, or ‘sculptable’, polymerisation shrinkage or contraction stress is still the most important clinical challenge or problem associated with their use. This shrinkage or contraction and the stress created varies from composite to composite, and can be affected by: its filler type and loading content, the resin matrix and its molecular weight, the shade and opacity, the cavity preparation shape (C-Factor) width and depth, the composite thickness, the elastic modulus of the composite and tooth, the irradiance level and curing time, the spectral output of the curing light, the curing light placement, bulk or incremental fill, the rate of force development (high irradiance lights), the initiator system used, and the degree of conversion. In published studies, shrinkage values for various composites have been reported from 2.00 to 5.63 vol. per cent, and 1.67 to 5.68 per cent, with flowables demonstrating the highest shrinkage with contraction stress measurements ranging from 3.3 to 23.5 MPa. Not all composites advertised as low-shrinkage actually have reduced polymerisation shrinkage measurements. When evaluating seven low-shrink BisGMA-based composites, Aelite LS Posterior and N’Durance presented relatively high shrinkage values.

The polymerisation contraction of the composite resin and contraction stress created, as discussed previously, can produce tensile forces on the tooth structure and the bonding system that may not only disrupt the bond to the cavity walls but also fracture enamel along the prisms (white line margins). This failure can lead to caries, sensitivity in vital teeth, and microleakage, allowing the penetration of bacteria, fluids and toxins which can negatively affect the success of endodontic treatment (coronal leakage). Braga et al state that ‘shrinkage stress development must be considered a multifactorial phenomenon’ and that ‘the volume of the shrinking composite becomes a variable to be considered’. Unterbrink and Liebenberg in their publication state that shrinkage stress increases with increasing C-Factor and that the size of the restored cavity is an important factor when bulk filling. Their study also shows that incremental filling lowers the C-Factor and that it is better than bulk cure because of better adaptation to the cavity wall, decreasing microleakage and increasing the degree of conversion. In a study looking at microleakage and cavity dimensions, it was found that microleakage seemed to be related to a restoration’s volume, but not to its C-Factor. With bulk filling techniques, the hardness or conversion of composites are significantly lower than those of the same material placed with the incremental technique. Watts et al recommend that the restorative mass must be equally considered when translating shrinkage science into specific clinical recommendations.

Fig. 3, Radiographic presentation of a patient with pain in the lower left second molar, which has been minimally restored.

Fig. 4, The clinical presentation of the second molar which would demonstrate sufficient tooth structure remaining after root canal treatment so that a fibre post and core is not required.

Fig. 5, Magnified view of the distal ridge of the second molar demonstrating a vertical crack.
So where does this lead us in a suggested modification of our restorative technique for placing a core in an endodontically treated tooth? Currently, when there are enough walls and tooth structure left, many clinicians insert a bulk fill, dual-cure composite resin into the endodontic access opening (the same material as that used for cementing the fibre post) and then cure it all at once with an LED curing light. As already mentioned, this bulk fill not only creates a challenge for proper depth of cure and maximum physical properties on polymerisation, which will be addressed later in this article, but the large volume/amount of composite inserted, negatively affects the integrity of adhesion and increases microleakage. The typical access opening, which is essentially a very deep Class I cavity preparation, not only requires a large amount of composite, but as well, places the composite in the highest C-factor cavity preparation configuration of five. Only when utilising a composite deep in the prepared root canal, has the C-Factor claimed to be higher at 200 to infinity.39

The suggested solution to the high polymerisation and contraction stress caused by bulk filling the access opening is to reduce the mass or bulk of composite by placing multiple Fiber Post Segments into the composite mass, before curing with the LED light. It has been conclusively shown that even when the C-Factor is at 200 or more in a prepared root canal, minimizing the thickness of the composite (the mass), results in less contraction stress (S-Factor) which increases the patency of the bond to the root canal walls decreasing microleakage.40-43 Of course, the placement of inserts into composite is not a new idea. Glass ceramic inserts and beta quartz have been used to decrease composite volume and later silica glass and ceramics were introduced as a method for post-composite insertion bulk reduction.44-46 These techniques demonstrated increased marginal patency and less microleakage, but the inserts were difficult to contour and polish with adhesion between the inserts and the composite being a challenge.47,48 Composite megafillers were introduced later, as these were essentially the same as the matrix of the bulk filled composite, eliminating the inherent chemical differences between the materials.49,50 The authors suggest the insertion of multiple high quality, high capacity, light conducting fibre post segments (not all fibre posts conduct light efficiently51,52). This is not only to reduce the composite volume, thereby minimizing the potential for microleakage, but is also equally as critical to use the light conductance of the fibre post segments to significantly increase the degree of polymerization of the dual-cure composite resin cements/core materials deep in the access opening, thereby increasing their physical properties.53

In their review of polymerisation shrinkage, Cakir et al discuss the attenuation of light, which
means that the deeper layers of composite resin are less cured with reduced mechanical properties, and that bulk filling shows significantly less hardness. Others have also shown that bulk placement and increased cavity depth result in a significant decrease in the effectiveness of polymerization, regardless of the exposure time. The ADA Professional Product review on Restorative Materials evaluated the depth of cure of 38 restoratives with ranges of 1.2 to 5 mm, with a core material CompCoreAF syringeMix Flow (W) being the lowest depth of cure at 1.2 mm. Included in the study were measurements of maximum polymerisation shrinkage stress showing that LuxaCore Dual Smartmix W was the highest in stress MPa of the core materials tested, with Clearfil Photo Core (T) showing the highest development of shrinkage stress rate.

Dual cure composite materials show the best physical properties and best polymerisation with sufficient light exposure, even though they are claimed to polymerise in the absence of light and ‘there is no evidence for a substantial chemically induced polymerisation of dual cure resins that occurs after light exposure is completed.’ This reality is especially critical for dual-cure self-adhesive resin cements Maxcem and RelyX Unicem, which show a better degree of conversion when they are light activated, with a lack of light activation decreasing the monomer conversion by 25 to 40 per cent and even in their dual cure mode, the decree of cure at best among the self-etch adhesives is only 41.52 per cent. Thus, the placement of a bulk filled dual cure composite into the endodontic access opening, followed by the placement of multiple fibre post segments that carry sufficient light energy to the depth of the occlusal floor of the access preparation, will increase the polymerisation conversion, resulting in a composite that demonstrates superior physical properties.

As a final comment, it has been proven that immediate high intensity light polymerisation creates the greatest polymerisation stress. Ilie et al state that ‘fast contraction force development, high contraction stress and an early start of the stress build up cause tension in the material with possible subsequent distortion of the bond to the tooth structure.’ This finding has been collaborated by many others in the scientific literature with resultant recommendations for a soft start or lower energy over a longer period of time. Miller states that ‘manufacturers continue to make outlandish claims of their curing capabilities, most of which fall into the ‘too good to be true’ category’ and Swift concludes that ‘the curing times recommended by a manufacturer might not deliver the amount of energy required to adequately cure composite, even under the ideal laboratory conditions’ that ‘very short curing times are not a good idea in most clinical situations’ and that ‘longer curing times are required.’ As well, Swift states that ‘instead of obtaining a boost, the “turbo” tip actually will reduce the amount of light reaching the composite to initiate the polymerisation process.’

Fig. 11. Multiple MacroLock X-R0 (Clinical Research Dental) fibre post segments (covered with a bonding agent which is first light cured) are verified for fit into the distal and two mesial canals.

Fig. 12. The Cosmecore A2 is injected into the bottom of the pulpal area filling to one half of the crown height, followed by the placement of the MacroLock X-R0 segments at the canal orifices.

Fig. 13. Occlusal view of the Cosmecore placed half way up the coronal tooth structure with the three segments placed. This first layer was light cured and followed with the completion of the final Cosmecore layer cured for 20 seconds.

Fig. 14. Post-operative radiograph of the completed restoration.
The tooth is now ready for a full coverage crown or onlay to protect the clinical crack.

Fig. 15  Occlusal view of the final restoration, trimmed and adjusted to the occlusion. The tooth is now ready for a full coverage crown or onlay to protect the clinical crack.

_Clinical case_

A 64-year-old female presented to the endodontic office with an uneventful medical history. She complained of spontaneous pain on the lower left side of one week’s duration, which radiated up the ramus of the jaw and was causing headaches. She also complained of hot and cold sensitivity with pain on biting. Clinical tests revealed pain to cold, which lingered for five minutes and a sharp electric like pain when a tooth sleuth was placed over the DL cusp tip. A distal crack was visualised. There was no periodontal pocketing. All other mandibular left and maxillary left teeth tested vital and asymptomatic. The radiograph revealed a small shallow minimally invasive amalgam restoration (Fig. 3). The diagnosis was Cracked Tooth Syndrome with an irreversibly inflamed pulp. The patient was advised of the questionable long term prognosis with cracked teeth yet decided to try and retain it understanding that if the crack extends in the root proper and a periodontal pocket develops, then extraction with an implant replacement may be a viable solution.

Due to the minimal invasiveness of the restoration, it is anticipated that after endodontic treatment, there would be enough coronal tooth structure left to allow for the preparation of a full coverage restoration with a fully circumferential ferrule of at least 2+ mm in height, as well as width (Fig. 4). Figure 5 is a magnified view of the distal vertical crack, with the wear facet on the lingual cusp indicating a working side contact interference. Endodontic therapy was initiated under the microscope and after a thorough debridement and shaping of the root canal spaces (Fig. 6), the roots were obturated with gutta percha using a continuous wave of condensation technique to a level 2 mm below the pulpal floor (Fig. 7). Phosphoric acid etching was initiated with the placement of Ultra-Etch Etchant (Ultradent) followed by microbrush agitation to work the etchant into the dentine, a thorough rinse, and light air drying (Fig. 8). Figure 9 shows the application of MPA bonding agent (Clinical Research Dental) with a microbrush, which again was followed by agitation to facilitate deeper penetration of the bonding agent, followed by evaporation of the solvent for ten seconds. The bonding agent was cured with a Valo Curing Light (Ultradent) for ten seconds utilising a Valo Proxiball Lens (Fig. 10). The Macro-Lock X-RO segments are verified for fit over the three canal orifices, and then coated with MPA bonding agent, which was cured for ten seconds (Fig. 11). Cosmecore (Cosmedent) A2 is injected into the pulpal chamber one half way up the occlusal height of the clinical crown (Fig. 12). The Macro-Lock X-RO segments are inserted into the Cosmecore followed by a 10 second cure with the Valo (Fig. 13). The rest of the occlusal access opening is filled with the Cosmecore and thoroughly cured with the Valo for 20 seconds. Figure 14 is the final post-operative radiograph showing the placement of the fibre segments into the core. The final restoration of the occlusal access opening is shown in Figure 15 after trimming and occlusal adjustment. The endodontically treated tooth is now ready for a final restoration.

This article has recommended restoring the teeth that meet the criteria for not needing the placement of fibre posts because of sufficient remaining tooth structure, with the use of multiple fibre post segments placed into the dual-cure composite cores of endodontically treated teeth based on the above evidence. This will decrease the overall polymerisation contraction and stress formation, thereby reducing occlusal microleakage, while at the same time driving the dual-cure composite to a better overall cure or conversion for better physical properties.

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Anatomical pin: A clinical case report

Authors: Profs. Frederico dos Reis Goyatá & Orlando Izolani Neto, Brazil

Introduction

Endodontic treatment of teeth with significant coronal destruction is a very common clinical procedure in the restorative clinical practice. When we are faced with this clinical situation, there will be an eminent need for the use of intra-radicular retainers to obtain greater stability and retention of the restoration to the remaining teeth.\(^1\)\(^,\)\(^2\)

The use of an anatomical pin is proposed for the rehabilitation of anterior teeth with extensively compromised root canals and with significant loss of dentine tissue.\(^2\) In this restorative method, in addition to...
The fibreglass pin, a compound resin is used to model the radicular conduit with the objective of reducing the space that would be filled by the resin cement. In this way, the combination of two restorative materials (pin and compound resin) will serve and behave biomechanically as a replacement of the dentine structure lost.  

Anatomical pins have an extremely favourable prognosis in cases of fragile roots due to loss of dentine structure and they contribute significantly to the rehabilitation of the tooth in terms of both masticatory function and aesthetics. In addition, the fibreglass pins have a more uniform distribution of tension in the occlusal and radicular regions compared with metal pins. Etching and silanisation of the pins are of the utmost importance for promoting interfacial adherence, especially in the region prepared for the core.

This study reports on a clinical case that demonstrates the preparation technique for the anatomical pin, using fibreglass pins and compound resin, in a maxillary central incisor with weakened roots, with the objective of re-establishing the coronal portion of the tooth.
Case report

A young male patient came into the integrated dentistry clinic at Universidade Severino Sombra needing restorative treatment of tooth #21. In the clinical and radiographic examination, significant coronal destruction and satisfactory endodontic treatment were noted (Figs. 1–3).

Restoration with an anatomical pin was proposed to the patient, in order to recover the function and aesthetics of the tooth and provide for future rehabilitation of the tooth with a full ceramic crown.

First, the decayed tissue was removed from the remaining tooth structure and the fibreglass pin was selected (Exacto #3, Angelus), as well as the accessory pins (Reforpin, Angelus; Fig. 4). The radicular conduit was isolated with mineral oil and the compound resin was applied (Fill Magic NT Premium, Vigodent/COLTENE) over the remaining tooth (Figs. 5 & 6) with the aid of a #1/2 Suprafill spatula (SS White). After filling of the conduit with resin, the Exacto pin and the pre-silanised accessory pins (Silano, Angelus) were inserted with the application of an adhesive (Fusion-Duralink, Angelus; Figs. 7–9). Next, the initial photoactivation was conducted on the pin and resin for 20 seconds.
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Finally, the coronal reconstruction was performed with the previously used compound resin in incremental portions and photoactivation was conducted (Figs. 10 & 11). A marking was made on the most incisal portion of the pins to guide the subsequent cropping of the pins (Fig. 12). The anatomical pin was then removed and the final photoactivation was performed for 40 seconds (Fig. 13). Soon after, the pin was adapted to the remaining coronal structure (Fig. 14).

After the preparation phase of the anatomical pin and coronal portion of the core with compound resin, preparation for adhesive cementation to the remaining tooth began (Fig. 15). Acid etching of the pin was performed for 30 seconds, and then it was washed and dried. The silane was then applied (Silano) for 20 seconds, as well as the adhesive (Fusion-Duralink) with subsequent photoactivation for 20 seconds (Figs. 16–18).

After the anatomical pin had been prepared, acid etching was performed on the remaining tooth for 20 seconds, followed by washing and drying it lightly to leave the dentine moist (Fig. 19). The dentine primer and the adhesive (Fusion-Duralink system) were applied and then photoactivated for 20 seconds (Fig. 20).

The cementation was done with auto-polymerisable resin cement, waiting a period of five minutes for the cement to chemically set (Figs. 21 & 22). Once the cementation of the anatomical pin was finished, the adhesive was applied to the coronal portion and photoactivated for 20 seconds, and the compound resin was applied in incremental portions for creation of the core (Figs. 23 & 24).

In order to complete the restorative process, the prosthetic preparation of the core was performed for future seating of a full ceramic crown (Fig. 25).

**Conclusion**

The anatomical pin constituted a clinical alternative for coronal and radicular reconstruction of endodontically treated teeth with significant destruction of dentine. In addition to rehabilitating the tooth, this clinical approach promotes a more balanced distribution of masticatory forces without compromising the remaining tooth structure, minimising the risk of radicular fracture. Moreover, this restorative alternative provides the possibility of an aesthetic result with the use of a metal-free full crown.

Editorial note: A complete list of references is available from the publisher.

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Shaping canals with confidence: WaveOne GOLD single-file reciprocating system

Author_ Dr Julian Webber, UK

_The mechanical and biological objectives of shaping root canals were beautifully described by Herbert Schilder in 1974. As relevant today, in the era of automated canal preparation techniques, as they were in the days of hand preparation techniques, these objectives provide the rationale for the designs, tapers and tip sizes of modern-day endodontic instruments. Shaping the root canal facilitates 3-D irrigation and cleaning of the root canal system of all pulp tissue, bacteria and their related by-products. Importantly, shaping the root canal provides the resistance form and facilitates filling the root canal system._

_From hand to rotary_

When manually shaping canals with multiple sequences of stainless-steel files and Gates-Glidden drills, root canal preparation techniques, old and new, have many deficiencies and iatrogenic problems, such as blocking, ledging, transportation and perforation, are common. The use of nickel-titanium (NiTi) files in continuous rotation driven by a dedicated endodontic motor capable of speed and torque control maintains the original pathway of the canal while limiting the amount of apically extruded debris. However, while the advantages of continuously ro-
Cyclic fatigue, caused by the structural alteration and work hardening of the metal, is induced by repeated tensile-compressive stress, especially when preparing canals exhibiting curvature. Torsional failure caused by using too much apical force occurs more frequently than flexural fatigue. Specifically, taper lock results when an excessive length of a file’s active portion binds in the canal during rotation. Un-desirable taper lock promotes torsional failure and file breakage. When the canal diameter is narrower than the diameter of the rotating file, the latter has limited ability to progress deeper into the canal, binds and then potentially unwinds and/or breaks.

**From rotary to reciprocation**

While the majority of commercially available NiTi systems are mechanically driven in continuous rotation, reciprocation—defined as any repetitive up and down or forward and reverse movement—has been used to drive endodontic instruments since 1958. Early attempts at reciprocation utilised alternating, but equal, forward and reverse angles of either 90 degrees or, more recently, smaller angles of 30 degrees. As such none of these instruments ever complete a full rotation. Although these reciprocating systems offer an alternative to manual preparation, multiple-file sequences, apical transportation, reduced cutting efficiency, inward pressure and limited debris removal remain issues. However, with a novel reciprocating movement of unequal bidirectional angles that complete a full forward rotation of 360 degrees after four 90-degree cutting cycles of reciprocation, just one single file can start and fully complete the preparation of a canal to a perfect shape. A single-file technique in conjunction with a novel reciprocating movement has been clearly shown to reduce both cyclic fatigue and torsional failure, preventing broken instruments.

In 2008, the concept of the “single-file technique” was adopted by DENTSPLY International as a project in collaboration with eight international clinicians to produce a more optimal, dedicated, safe, unique reciprocating single file and to identify the most suitable unequal bidirectional angles with a motor system to generate this movement. The outcome was the launch of RECIPROC (VDW) in 2010 and WaveOne (Dentsply Maillefer) in 2011. Both systems were marketed as simple, efficient and predictable automated methods to shape canals and embraced by many general dental practitioners looking to move into automated canal shaping after years of unsuccessful attempts with manual techniques and valued both in terms of time and cost savings.
WaveOne and RECIPROC file systems (reciprocating files) demonstrate considerably improved mechanical properties, superior to rotary files. While the cyclic fatigue properties of RECIPROC are superior to WaveOne, the resistance to torsional failure of WaveOne is superior to RECIPROC. Overall, reciprocating files are more resistant to fracture than are continuously rotating files, extrude less debris than do conventional multiple-file rotary systems and eliminate bacteria from root canal systems as efficiently as rotary systems. The shaping ability of reciprocating files is as good as and in many cases better than rotary files. Finally, it can be clearly stated that reciprocating files do not induce dentine cracks.

WaveOne and RECIPROC were designed as true single-use instruments that cannot be sterilised and re-used. The ISO colour-coded ABS ring on the handle expands if sterilised and the file will not fit into its handpiece. Single use is based on sound scientific facts and common sense, as elimination of repeated use decreases the possibility of fracture due to both fatigue and torsional failure. The inability to consistently clean and sterilise used instruments eliminates any concerns about cross-contamination, and disposal after single-patient use eliminates the cost of disinfecting, cleaning and sterilising, reducing costs overall. However, it should be understood and fully appreciated that a single reciprocating file performs the same task that would typically require three or more rotary NiTi files to accomplish. Logic dictates that single use is by far the best solution to reducing the incidence of file breakage with all its ethical, emotional and malpractice ramifications.

With today’s increased focus on minimally invasive endodontics, the conclusions from the literature and taking into account feedback from clinicians using WaveOne since its introduction in 2011, four of the original opinion leaders involved in the initial development of the file, Drs Clifford Ruddle (US), Sergio Kuttler (US), Wilhelm Pertot (France) and Julian Webber (UK), worked in collaboration with the research and development team at DENTSPLY in Bal-laignes, Switzerland, to further improve the cutting efficiency and mechanical properties of the file and give a new level of confidence to the many clinicians still wary of automated techniques for shaping canals.

The result is the recent launch of WaveOne GOLD, a new generation of reciprocating files offering simplicity, safety and single use in shaping canals.

WaveOne GOLD instruments are manufactured utilising a new DENTSPLY proprietary thermal process, producing a super-elastic NiTi file. The gold process is a post-manufacturing procedure in which the ground NiTi files are heat-treated and slowly cooled. From a technical perspective, the heat treatment modifies the transformation temperatures (austenitic start and austenitic finish), and this has a positive effect on the instrument properties. While this process gives the file its distinctive gold finish, more importantly, it considerably improves its strength and flexibility far in excess of its predecessor. DENTSPLY internal testing has shown the following: the cyclic fatigue resistance of WaveOne GOLD Primary is 50% greater than that of WaveOne Primary (which itself was twice as great as most standard rotary file systems), and the flexibility of WaveOne GOLD Primary is 80% greater than that of WaveOne Primary.
Design features

There are four tip sizes in the WaveOne GOLD single-file reciprocating system: Small (20.07, yellow), Primary (25.07, red), Medium (35.06, green) and Large (45.05, white) (Fig. 1a), available in 21, 25 and 31 mm lengths. The various tip sizes and tapers afford the clinician the ability to clinically prepare a wider range of apical diameters and endodontic anatomy commonly encountered in daily practice. Canal preparations that have sufficiently tapered resistance form are ideal for irrigant exchange and removal of debris, thus promoting 3-D disinfection and filling of the root canal system.

WaveOne GOLD has active cutting lengths of 16 mm, shortened 11 mm handles for improved posterior access and the same expanding ISO colour-coded ABS ring as WaveOne, maintaining the philosophy of single use. Variable and reducing tapers ensure a more conservatively shaped canal with greater preservation of tooth structure at D16, the coronal extent of the preparation (Fig. 1b). While the concepts of “minimally invasive endodontics” lack documented and meaningful studies, any shaping objective that removes less of the existing tooth structure while optimising efficient 3-D irrigation and obturation is a positive step in an effort to preserve the integrity of the natural tooth.

The cross-section of WaveOne GOLD is a parallelogram with two 85-degree cutting edges in contact with the canal wall, alternating with a patented DENTSPLY off-centred cross-section where only one cutting edge is in contact with the canal wall (Fig. 2). Decreasing the contact area between the file and the canal wall reduces binding (taper lock) and, in conjunction with a constant helical angle of 24 degrees along the active length of the instrument, ensures little or no screwing in. The additional space around the instrument also ensures additional space for improved debris removal. The tip of WaveOne GOLD (Figs. 3a & b) is ogival, roundly tapered and semi-active, modified to reduce the mass of the centre of the tip and improve its penetration into any secured canal with a confirmed, smooth and reproducible glide path.

Collectively, these design features result in a reciprocating movement that is very smooth, eliminating the need to push on the file, and thereby promoting safety and considerably improving cutting efficiency. This reduces shaping time by a further 19% in canals when compared with WaveOne.

Reciprocating movement

WaveOne GOLD files are designed with a reverse cutting helix, engage and cut dentine in a 150-degree counter-clockwise (CCW) direction and then, before
the instrument has a chance to taper lock, disengages 30 degrees in a clockwise (CW) direction. The net file movement is a cutting cycle of 120 degrees and therefore after three cycles the file will have made a reverse rotation of 360 degrees (Fig. 4).

The X-Smart iQ (Fig. 5) launched in conjunction with WaveOne GOLD is an endodontic motor and cordless 8:1 handpiece designed for reciprocation and continuous motion. The handpiece is Bluetooth controlled by a DENTSPLY Apple iOS iQ app downloaded on to an iPad mini 2 (Apple). As a complete digital solution, it is designed for all stages of the endodontic procedure, including patient management, file selection, torque control training and patient education. The X-Smart iQ also offers electronic apex locator functionality. Currently available DENTSPLY reciprocating file motors and their respective handpieces, the X-Smart Plus motor (Rest of the World) and ProMark and e3 Torque Control motors (North America), can be used without modification when using the complete range of WaveOne GOLD files. All reciprocating file motors are preprogrammed to produce the reverse bidirectional movement, but the CCW/CW angles, torque and speed settings cannot be altered. These motors can, of course, be used for continuous rotation when the clinician is able to adjust the speed and torque, as desired.

**Shaping technique (Fig. 6)**

The WaveOne GOLD Primary (025.07) is always used first to initiate the shaping procedure. It will create optimal shape in approximately 80% of canals as a true single-file technique and is used in canals that have a confirmed, smooth and reproducible glide path. An expanded glide path is a perfect set-up for the safe apical progression of any mechanically driven endodontic file.10

The WaveOne GOLD Small (020.07) file should be thought of as a bridge file, as the resulting shape is considered too small to allow disinfection and filling of the root canal system. When the Primary file will not passively advance through the glide path, which has been verified to length, the Small file is used to transition and expand the shape. The Primary file is then re-utilised to reach the full working length. Although a two-file sequence is the exception, this method must be considered a safer and more efficient option compared

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**Fig. 8** A ProGlider progressing apically expands the glide path.

**Fig. 9** WaveOne GOLD Primary progressing apically through the expanded glide path.

**Fig. 10** WaveOne GOLD Primary at full working length.

**Fig. 11** WaveOne GOLD Primary loaded with debris, especially in the apical extent of the file, indicating that full shape has been achieved.

**Fig. 12** WaveOne GOLD obturating solutions with matching paper points, gutta-percha points and Thermafil.
new product technique  _shaping canals_

with most other commercially available rotary shaping techniques.

After the Primary file reaches length, the flutes are inspected and if full of debris would indicate shaping is finished. If the Primary file is loose at length with no dentinal debris on the apical flutes, shaping continues with WaveOne GOLD Medium and/or WaveOne GOLD Large until the apical flutes are loaded. Apical gauging with ISO #25 or 35 hand files, respectively, will also confirm whether the apical foramen diameter is larger and that a Medium or Large file is required.

WaveOne GOLD files are used in a brushing action to reduce resistance and more effectively instrument canals that exhibit irregular cross-sections. Brushing eliminates coronal interferences, creates lateral space, and promotes the inward advancement of the file. Further, a brushing action reduces the contact between the file and dentine, mitigates undesirable taper lock, and allows the instrument to run more freely. In order to avoid transportation, never brush at length. The files are used with a gentle inward ‘stroking’ motion of short 2–3 mm amplitude, to passively advance the file along a smooth, reproducible glide path.

Reduced shaping time with WaveOne GOLD means there is more time available to focus on active irrigation methods. In order to enhance irrigation and improve effectiveness activation with sonic and ultrasonic irrigation is now well accepted. Dynamic irrigation in the apical one-third of highly curved canals has been shown to significantly improve disinfection.32

The stages of the shaping procedure can be summarised as follows (Figs. 7a–c):

- Establish straight-line coronal and radicular access with emphasis on flaring, flattening and finishing the internal axial walls.32
- In the presence of a viscous chelator, use a #10 hand file to verify a glide path to length. In more restrictive canals, use a #10 hand file in any region of the canal to create a glide path.
- Expand this glide path to at least 0.15 mm using either a manual or a dedicated mechanical file, such as the ProGlider or PathFile (DENTSPLY) (Fig. 8).
- Initiate the shaping procedure with the Primary file in the presence of sodium hypochlorite (Fig. 9).
- Use gentle inward pressure and let the Primary file passively progress through any region of the canal that has a confirmed glide path. After shaping 2–3 mm of any given canal, remove and clean the

| Table 1. WaveOne GOLD tips. |

Figs. 13a–c & 14a–c. The series of pre- and post-op radiographs of tooth #26 demonstrates the ability of WaveOne GOLD to shape considerable curvatures in canals that are long, curved and narrow, following the apical anatomy. All canals were obturated with WVC.
Primary file, irrigate, recapitulate with a #10 hand file and re-irrigate. Continue with the Primary file, in two to three passes, to pre-enlarge the coronal two-thirds of the canal. In more restrictive canals, use a #10 hand file in the presence of a viscous chelator and negotiate to the terminus of the canal. Gently work this file until it is completely loose at length. Establish working length, confirm patency and verify the glide path. Expand this glide path to at least 0.15mm using a manual or mechanical glide path file. Carry the Primary file to the full working length (Fig. 10) in one or more passes. Upon reaching working length, remove the file to avoid over-enlarging the apical foramen. Inspect the apical flutes; if they are loaded with dentinal debris, then the shape is finished (Fig. 11).* If the Primary file is loose at length with no dentinal debris on the apical flutes, continue shaping with the Medium or Large file.

Obturation solutions

Obturation of the root canal system is the final step of the endodontic procedure. The WaveOne GOLD system includes matching paper points, gutta-percha points and Thermafil obturators (Fig. 12). The new nanotechnology-engineered gutta-percha points with their extended heat flow are ideal for all warm vertical compaction (WVC) techniques (Figs. 13a–c, 14a–c & 15a–c). WaveOne GOLD shapes can also be effectively obturated with GuttaCore (DENTSPLY), the cross-linked gutta-percha core obturator.

Conclusion

WaveOne GOLD is a safe, efficient and simple system for preparing canals. Sophisticated metallurgy and design result in improved flexibility and cyclic fatigue life with less binding and torsional stress on the file during work. The fear of instrument breakage should be eliminated for many clinicians by using WaveOne GOLD. Root canal preparation with WaveOne GOLD is very cost-effective, since 80% of cases can be completed with the single Primary instrument. Single use eliminates the need to spend valuable time and unnecessary expense in sterilising procedures, with further benefits in cost savings. Faster preparation time allows the clinician to focus on the most important aspect of clinical endodontics, disinfection, thus fulfilling the mechanical and biological objectives of shaping canals.

WaveOne GOLD has set a new standard and shaping canals with confidence is now a clinical reality for all.

Editorial note: The author has a commercial interest in WaveOne and WaveOne GOLD file systems.

A list of references is available from the publisher.

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about the author

Dr Julian Webber has been a practising endodontist in London, England for over 35 years. He was the first UK dentist to receive a master’s degree in endodontics from a university in the USA (Northwestern University, Chicago, IL) in 1978. He has lectured extensively and given many hands-on courses on endodontics worldwide. He has published in numerous peer-reviewed journals and contributed numerous chapters to endodontic texts.

Dr Webber is a former President of the British Endodontic Society and American Dental Society of London, a faculty member of the Pacific Endodontic Research Foundation in San Diego, CA, Honorary Professor at the University of Belgrade in Serbia, and an honorary member of the Ukrainian Medical and Stomatological Academy. He is a fellow of the International College of Dentists and an active member of the American Association of Endodontists. He is the editor-in-chief of *Endodontic Practice* (UK) and a board member of many prestigious dental journals.
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A short history of the NiTi file revolution

Author_ Dr Barbara Müller, Germany

Nowhere in dentistry is technical progress as rapid as it is in modern endodontics. The development of flexible nickel-titanium (NiTi) files in the late 1980s created entirely new and hitherto unknown opportunities in the mechanical preparation of root canals. The following article gives a descriptive explanation of the decisive technical differences between a conventional file system and the latest generation of instruments. Employing a number of different scenarios, the article examines the opportunities available to ENDO specialists and beginners through the smart application of modular NiTi systems in different treatment situations.

Numerous innovations have made work significantly easier for endodontists over the past few years. There can be little doubt that the introduction of rotary files made of nickel-titanium alloys is a major milestone. But what exactly is the secret behind this versatile material? Nitinol alloys generally consist of approximately 55% nickel and up to 45% titanium. It is this combination that lends the material its pseudo-elastic deformation properties. The second outstanding feature is the option of giving the material a shape memory. Back in 2011, the Swiss dental specialist COLTENE had already developed a method for modifying the ‘DNA’ of NiTi, in which the files were given a true shape memory and thus allowed exceptionally precise working. In future, dentists were to be in a position where even strongly curved canals could be prepared safely and confidently without having to fear unexpected breaking of the instrument. The largely tension-free behaviour of this new file generation caused quite a sensation in the industry, as it had hitherto not been possible to simply bend NiTi files by hand. The widely varying use of physical terminology over the years has been confusing, so to give a clearer understanding of what NiTi systems with a ‘controlled memory’ effect can offer, it pays to take a more profound look at the physical and molecular relationships.
Two types of deformation

The use of files in the root canal unavoidably leads to deformation of the file material. If we take classical rubber, probably the best known elastic deformable material, the issue is clear: if one stretches a rubber elastic band (Fig. 1) it generally returns to its previous shape by itself as soon as force is no longer applied. During this process, the applied energy escapes and this can be clearly measured at a physical level. Using a thermometer, the reversal of the stretching process shows a slightly increased temperature of the material (Fig. 2a). This type of deformation is elastic and completely reversible at the same time. Examination of the molecular structure of the rubber shows there are no changes to the molecular bonds. A comparable example for the elastic deformation of metals is the thin metal spiral children’s toy, which, after an initial shove, runs down stairs automatically and repeatedly several times without showing any visible signs of fatigue of the material (Fig. 2b).

The second type of deformation is plastic deformation. This type of plastic deformation is well known to anyone who has ever been involved in a car accident with damage to the car’s bodywork. The damage is usually irreversible, even if the dents have been repaired and resprayed. The reason is the change in the molecular structure of the metal (Fig. 3) where the bonds change and the molecules diffuse (Fig. 4). In case of a repeat collision with such a previously damaged car, the damaged car door or passenger compartment will buckle much more readily as the new molecular structure has an extremely negative effect on the overall stability of the material. It goes without saying that respraying the traces of an accident adds only little mechanical resistance to the car; in dentistry, the differentiation between elastic, transient deformation and irreversible, plastic deformation is at least equally important. A plastically deformed NiTi file will break too easily due to material fatigue, and plastic deformation can usually not be detected under a magnifying glass or microscope, let alone with the naked eye, due to the high bounce-back effect of conventional NiTi material. Minute and also invisible microfractures that occur during the metal cutting manufacturing process can increase the risk of unexpected breaking of the instrument. Put into plain words, this means that the pseudo-elasticity of conventional NiTi files often masks existing plastic deformation: visibly, the damaged file does not differ from an unused file, but the consequences during preparation can be serious. Until now, the treating dentist had no opportunity of checking the actual condition of the used instruments by himself, even the use of disposable files offers no guarantee, although it does increase safety somewhat.

Shape memory increases safety

With the development of a new generation of NiTi files, COLTENE finally solved this quality control problem with a very simple trick. Meanwhile it has become possible to differentiate between the elastic and plastic deformation of nickel-titanium alloys. To achieve this, the material used must possess a true shape memory. Ultimately, shape memory is nothing else but ‘training’ the material to ‘memorise’ a certain shape under different conditions. After deforming the material by bending or similar means, a material with shape memory automatically returns to its original shape as soon as the external conditions are changed. Temperature or pressure deviations are examples of such changed parameters. Alternatively, one can induce a return to the original position through magnetism or via a simple chemical process.

Applied to endodontic instruments, the practical advantages of this principle are soon evident: a NiTi file with a ‘controlled memory’ effect adopts the...
Like a Phoenix from the ashes

The reason why Nitinol can be trained so reliably lies in its inner structure. NiTi alloys display two crystallographic phases: the austenite phase at high temperatures, and the martensite phase at rather lower temperatures. In the martensite phase, Nitinol can be bent into complicated structures without effort. Without further external influences, the bent NiTi file with ‘controlled memory’ effect therefore remains in this position at room temperature. In the austenite phase, i.e. at higher temperatures, the material can adopt its original structure and the molecules form a cubic face-centred lattice structure. Heat induces the phase transformation and the file returns to its original condition during sterilisation. This controlled bounce-back effect can even be demonstrated directly using a conventional lighter. When placed over the flame, the heated instrument visibly changes from its bent form back to the classical straight file shape in only a few seconds (Fig. 5).

Based on these insights, COLTENE presented its HyFlex CM file series for the first time in 2011. The abbreviation ‘CM’ stands for the above described ‘controlled memory’ effect. This special property results in an up to 300% higher fatigue resistance compared with conventional NiTi files, with an added highlight: the HyFlex CM excels through its extreme flexibility. Due to its special characteristics, the file adapts perfectly to prevailing canal anatomies and thus considerably reduces the risk of perforation. In addition, the instrument moves perfectly in the centre of the canal. This effectively prevents a shift in course or via falsa. The result is perfect cleaning and preparation of the root canal for subsequent...
obturation. Like a Phoenix from the ashes, the NiTi file is regenerated by autoclaving and ready for its next application until it reaches the end of its life cycle by clearly displaying an uneven, bent shape. The files are available pre-sterilised for dentists who prefer working with disposable instruments, especially as endo experts also benefit from the exceptional flexibility and fracture safety of HyFlex in single use.

Practical advantages of modular NiTi systems

Looking into the future, the trend is definitely moving towards modular NiTi systems. The advantage of such variable instrument sets is mainly given by their high degree of versatility. The considerable complexity of the human root canal anatomy always presents dentists with new challenges. Hidden isthmuses and side canals, but also horizontal lateral canals, can quickly turn patient cases into a journey into the unknown, especially as, depending on the type and position of the tooth, the X-ray findings do not always clearly identify all branches. Modular NiTi systems enable working with confidence in virtually every situation. Depending on the anatomical situation, the dentist can choose between fast instrumentation with only a few files or highly precise canal shaping with a skilful combination of different NiTi files.

High cutting performance through spark discharge

With the HyFlex EDM (COLTENE) the fifth generation of NiTi files has been recently presented at the IDS 2015. Spark erosion generates a unique, hardened surface, which improves cutting performance even further. Whereas classical NiTi files are traditionally milled on CNC machines, so-called Electrical Discharge Machining (EDM for short) processes the workpieces with the aid of electrical discharge. The repeated bombarding of the alloy with sparks melts the material or even leads to evaporation in some places. The result is a file with a distinctly textured surface where heat creates a new surface hardness, which – similar to a bread knife with serrated edge—displays particularly good cutting properties (Fig. 6).

The result of this innovative process is an unbreakable file, predestined for dentists who wish to realise reliable results quickly with a reduced file sequence. In particular, the HyFlex EDM facilitates working with rotary instruments for ENDO beginners; due to their enormous flexibility, the number of files used can be reduced significantly without making compromises in adapting to the natural root canal anatomy. In simple cases, two files are sufficient to clean and efficiently prepare the root canal as with the classical method. All that is required, is a slow speed handpiece which can be operated at up to 500 rpm at a recommended torque of up to 2.5 Ncm. To prepare a mechanical glide path, the dentist uses a 10/.05 Glidepath file, which is introduced up to the full working length with dabbing up and down movements (at 300 rpm). As soon as resistance is felt, check patency using a 20/.02 hand file. Final preparation in the central and apical area is then performed using the HyFlex EDM 25/. One File (400–500 rpm), also with gentle dabbing without applying pressure and progressing to the full working length (Fig. 7). Due to the high cutting efficiency, it is important to only proceed for 1–2 mm without applying pressure to clean the file in between and to rinse the canal thoroughly.

Optionally, the root canal can be extended coronally in advance using the 25/.12 Orifice Opener. In more complex cases, and depending on the clinical situation and the extent of curvature of the canal

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Fig. 5  "Controlled memory" effect.

Fig. 6  Surface of the HyFlex EDM under the microscope.
industry report NiTi files

Fig. 7 File sequence.

in question, the sequence for preparation can be complemented with sizes from the HyFlex CM range (i.e. 15/04, 30/04). Of special interest is the option of also preparing large canals safely with HyFlex EDM in the apical area using the Finishing Files in the sizes 40/04, 50/03 or 60/02, which are also extremely flexible. The novel system solutions available on the market have made the question of the ideal file sequence less of an issue. This uncomplicated handling has increasingly attracted dental practitioners to the supreme discipline of tooth preservation, and training of the entire practice team is relatively easy.

Conclusion

In the long term, modern instruments will increasingly support ENDO experts in their daily work. Sophisticated materials with so-far unexplored properties have the potential of defining completely new treatment standards in only a few years. We may soon be facing another paradigm shift to highly energetic or even entirely chemical-biological methods. A first taste of things to come is presently given by the 2-in-1 filling systems, where contact with fluids forms hydroxyapatite crystals, which also support regeneration in the root canal. This is yet a further milestone in materials research on the path to optimal endodontic therapy. The utilisation of natural, regenerative processes combined with the intelligent use of current technical options, will help both ENDO specialists and beginners to create sustainable solutions for a large number of indications.

about the author

Dr Barbara Müller
_Studies in Agricultural Biology at the University Hohenheim and Master of Science at the University of Georgia, USA;
_1993 PhD at the University of Ulm;
_1996–2010 R&D Manager at Coltène/Whaledent GmbH + Co. KG, among others, including responsibility for the development of products such as RoekoSeal, GuttaFlow or the HyFlex CM NiTi files;
_Manager Business Unit COLTENE ENDO;
_Guest speaker at numerous events of the European Dental and Endodontic Societies.
The DTI publishing group is composed of the world’s leading dental trade publishers that reach more than 650,000 dentists in more than 90 countries.

www.dental-tribune.com
Shaping the root canal system with the Hybrid Concept technique

Authors_ Drs Emanuele Ambu & Fabio Rovai, Italy

What is the worst nightmare for dentists? Endodontics is for many of them. Reading "endodontic treatment" in their organiser frightens them. Two of their main worries are instrument fracture inside a root canal and treatment of curved canals. There is also the concern of a ghost fourth canal, such as in a patient with persistent pain since treatment.

We do not have a solution to all of the problems, but we have solved many of them by introducing some notions to our shaping technique for root canal systems and using devices for checking the working length progressively.

We began our study some years ago by analysing the literature and realised that root canal shaping...
was being impaired by the use of stainless-steel instruments and this occurred more frequently with less skilled operators and more complicated clinical cases. According to a number of authors, shaping root canals with stainless-steel instruments gives rise to more ledges than with NiTi instruments, irrespective of whether they are used manually or fitted on suitable motors.\(^1\)\(^,\)\(^2\) This will lead to more failures in endodontic treatment. In one of their papers, Berutti and Colleagues stressed that unskilled operators (students) caused many more deformations in the middle third and apical third of the root canal using stainless-steel instruments than did skilled operators.\(^4\) However, this problem was reduced for unskilled operators using NiTi rotating instruments. In fact, the results obtained by students with NiTi rotating instruments were much better than those obtained by skilled operators using stainless-steel instruments. Based on these findings, we decided to avoid the use of stainless-steel instruments and to start treatment with NiTi instruments from the first file inserted into the canal.

But how do we work without going beyond the apex? On the one hand, stainless-steel instruments are the cause of the problem, especially with less skilled operators, and the more curved and complex the canal is, the more serious the problem. On the other hand, we cannot insert a rotating instrument unless we know exactly where the tooth ends. We can determine this using a device with an electronically controlled endodontic motor and a suitable electronic apex locator. We have found such systems in the DentaPort ZX with a high-precision electronic apex locator and the TriAuto mini kit (Morita). The device is connected to the patient through a cable and the instrument starts rotating once it is inserted into the canal. It stops working when it reaches the apical foramen. We have tested the precision of these devices with a simulator and the results confirmed that the system is highly reliable (Fig. 1).

Having solved one problem, we focused on reducing the fracture risk of instruments; the literature helped us in this case too. We were able to greatly reduce this risk by creating a glide path\(^5\)\(^,\)\(^6\) and removing any coronal interference.\(^7\) At this point, our technique, called “Hybrid Concept”, was starting to take form. We establish the glide path quickly using the thinnest rotating NiTi instrument available, \#1 EndoWave MGP (Mechanical Glide Path; Morita). We can therefore take advantage of the integrated electronic control of the devices already mentioned. We follow the same procedure in case of narrow or very curved canals, using the \#2 MGP (tip D of 15 mm) and \#3 MGP (tip D of 20 mm) files in very complex cases.
Afterwards, we remove any coronal interference using the 35.08 EndoWave file (Morita). It is a very short and strong instrument designed to perform this function quickly and safely. After reducing the risk of instrument fracture, we finally introduce a stainless-steel instrument up to the apical terminus to confirm the exact working length. We then perform the canal shaping in a few seconds by means of a 20.06 or 25.06 EndoWave file.

What best describes our Hybrid Concept technique? Safe (the instrument fracture risk is minimum), quick (only three steps), low risk of anatomic deformation (no use of stainless-steel instruments, especially in the delicate step of probing), predictable (because it is performed according to electronically guided endodontics). The less skilled the operator, the more effective this technique is. It has become even safer with the new motor DentaPort ZX Set OTR (Optimum Torque Reverse; Morita). It makes it possible to shape canals with rotating motion and reciprocating motion. Instruments rotate within the canal, but when the present torque level is exceeded, the reciprocating motion will start (90 degrees/
Instruments still go down to the apex, but with reduced fracture risk because the cyclic fatigue of this motion is interrupted.

In this case too, we have performed tests and verified that an instrument used like this, even under extreme conditions, will double its duration before breaking as compared with a rotating motion. All of the tests have confirmed this advantage both for new and used instruments. With the OTR kit, root canal shaping according to the Hybrid Concept has become even safer and quicker.

Is this technique suitable for all kinds of canals? Yes, it is, but it should be adjusted: the more curved and narrower the canal, the greater the need to use intermediate instruments. For example, the whole set of MGP files may need to be used in preparing the path and the 15.04 and 20.04 EndoWave files used before reaching the canal end with instruments with a 06 taper. With a little practice and prudence, we can safely shape even severely curved root canal systems.

Finally, we wish to offer a tip: use MGP files to shape the accessory mesiobuccal canal of maxillary molars. The #1 MGP file will quickly reach the apical terminus in cases in which even the smallest stainless-steel instrument would have stopped after few millimetres. After reaching the apical foramen safely, owing to the integrated electronic apex locator, the #15 and 20 MGP files will enlarge the canal, which can easily be refined.

In conclusion, we are most satisfied with this easy and predictable technique that transforms any endodontic treatment from a nightmare to a pleasant experience.

Editorial note: A list of references is available from the publisher.

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Figs. 9a & b, A difficult case: endodontic treatment of a mandibular left second molar (Dr Emanuele Ambu).

Figs. 9a & b, A difficult case: endodontic treatment of a mandibular left second molar (Dr Emanuele Ambu).

The Authors want to thank Dr Daniele Boari, Dr Federico Campedelli, Dr Elisa Cuppini, Dr Marianna Grossi, Dr Federica Peducci, Dr Giorgio Silvestri and Dr Marco Vigna for their help in performing the “Hybrid Concept technique”.

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Dr Emanuele Ambu is an active member of the Italian Society of Endodontics, an active member of the Italian Academy of Endodontics and a certified member of the European Society of Endodontontology.

Dr Fabio Rovai is an aggregate member of SIE and a member of Italian Academy of Endodontics.

Both authors are members of the Italian J Morita Opinion Leaders’ group.
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At the 17th ESE Biennial Congress in Barcelona (16–19 September 2015), MANI is proud to announce the global launch of their new and novel rotary nickel titanium file system, ‘MANI Silk’ at the booth 68.

MANI Silk features an innovative breakthrough in heat treatment technology. The files are heat treated from the tip through the first 10 mm of the cutting flutes, providing flexibility where it is needed most. In addition, the file has a teardrop cross-section, which channels debris coronally, reducing the ‘screwing in’ effect and improves tactile control, hence the name MANI Silk.

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FKG Dentaire in the 2015 ESE Congress

Market leader in endodontic instruments to take active part

_This year marks the first time_ FKG Dentaire will be a Bronze Sponsor of the event, which takes place 16–19 September at the International Conference Centre of Barcelona.

“The ESE Congress is incredibly important for us, as it brings together over 2,000 specialists in endodontics,” says Thierry Rouiller, CEO of FKG Dentaire. “It’s a unique opportunity in Europe to present our different products and demonstrate how they work. It also gives us a chance to share and exchange ideas with a group of passionate individuals coming from different perspectives.”

To mark the occasion, FKG Dentaire is focusing on the big picture. It has invited three distinguished endodontic experts who will present in detail a hand-picked selection of FKG instruments, including the company’s flagship product this year, the XP-endo Finisher.

Kicking off proceedings on Wednesday, 16 September, will be Dr Martin Trope from USA.

“We are honoured to have Dr Trope animate two pre-congress sessions organised by FKG on the theme of ‘Biologic and Conservative Endodontics: 3-D disinfection of the root canal system using memory shape technology’,” explains Patricia Borloz, marketing director at FKG Dentaire. “From shaping to obturation, participants at this hands-on lecture will be able to follow a step-by-step demonstration at the microscope.”

“On Thursday, Dr Gilberto Debelian from Norway will lead a lecture on the challenges of cleaning the root canal and present the characteristics and advantages associated with the XP-endo Finisher. This latest FKG innovation is a revolutionary instrument that allows practitioners to treat highly complex root canal systems and clean hard-to-reach areas with minimal impact on the dentine.”

“Finally, on Friday, 18 September, we have the pleasure of welcoming Dr Bertrand Khayat from France,” Ms Borloz adds. “He will showcase from start to finish a short sequence of exclusively rotary instruments developed by FKG to maximise the quality and efficiency of root canal preparation. We are really looking forward to these sessions and to hearing participants’ comments and suggestions.”

Advance online registration for pre-congress sessions, together with the full schedule of congress lectures, is now available on the ESE website: _www.e-s-e.eu_

For more information, please visit the FKG Dentaire stand in area 49/36 of the exhibition hall or get in touch using the contact details below._

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2015

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16–19 September 2015
Barcelona, Spain
www.e-s-e.eu

7th Annual Congress of Czech Endodontic Society
26 September 2015
Prague, Czech Republic
www.endodont.cz/en/

Austrian Society of Endodontology Annual Meeting
2–3 October 2015
Salzburg, Austria
www.oegendo.at

Uruguayan Endodontic Society Congress
5–8 October 2015
Montevideo
Uruguay
www.endorestauradorlaser.com

4th Pan Arab Endodontic Congress
29–31 October 2015
Hamamet, Tunisia
www.paec2015.org

BES 2015—British Endodontics Society Regional Meeting
20–21 November 2015
Southampton, UK
www.britishendodonticsociety.org.uk

ADF Meeting
24–28 November 2015
Paris, France
wwwadf.asso.fr

Great New York Dental Meeting
27 November–2 December 2015
New York, USA
www.gnydm.com

2016

AAE 2016 – American Association of Endodontists
6–9 April 2016
San Francisco, USA
www.aae.org

10th World Endodontic Congress
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_ all the image (tables, charts, photographs, etc.) captions;
_ the complete list of sources consulted; and
_ the author or contact information (biographical sketch, mailing address, e-mail address, etc.).

In addition, images must not be embedded into the MS Word document. All images must be submitted separately, and details about such submission follow below under image requirements.

Text length
Article lengths can vary greatly—from 1,500 to 5,500 words—depending on the subject matter. Our approach is that if you need more or less words to do the topic justice, then please make the article as long as or as short as necessary.

We can run an unusually long article in multiple parts, but this usually entails a topic for which each part can stand alone because it contains so much information.

In short, we do not want to limit you in terms of article length, so please use the word count above as a general guideline and if you have specific questions, please do not hesitate to contact us.

Text formatting
We also ask that you forego any special formatting beyond the use of italics and boldface. If you would like to emphasise certain words within the text, please only use italics (do not use underlining or a larger font size). Boldface is reserved for article headers. Please do not use underlining.

Please use single spacing and make sure that the text is left justified. Please do not centre text on the page. Do not indent paragraphs, rather place a blank line between paragraphs. Please do not add tab stops.

Should you require a special layout, please let the word processing programme you are using help you do this formatting automatically. Similarly, should you need to make a list, or add footnotes or endnotes, please let the word processing programme do it for you automatically. There are menus in every programme that will enable you to do so. The fact is that no matter how carefully done, errors can creep in when you try to number footnotes yourself.

Any formatting contrary to stated above will require us to remove such formatting before layout, which is very time-consuming. Please consider this when formatting your document.

Image requirements
Please number images consecutively throughout the article by using a new number for each image. If it is imperative that certain images are grouped together, then use lowercase letters to designate these in a group (for example, 2a, 2b, 2c).

Please place image references in your article wherever they are appropriate, whether in the middle or at the end of a sentence. If you do not directly refer to the image, place the reference at the end of the sentence to which it relates enclosed within brackets and before the period.

In addition, please note:
_ We require images in TIF or JPEG format.
_ These images must be no smaller than 6 x 6 cm in size at 300 DPI.
_ These image files must be no smaller than 80 KB in size (or they will print the size of a postage stamp!).

Larger image files are always better, and those approximately the size of 1 MB are best. Thus, do not size large image files down to meet our requirements but send us the largest files available. (The larger the starting image is in terms of bytes, the more leeway the designer has for resizing the image in order to fill up more space should there be room available.)

Also, please remember that images must not be embedded into the body of the article submitted. Images must be submitted separately to the textual submission.

You may submit images via e-mail, via our FTP server or post a CD containing your images directly to us (please contact us for the mailing address, as this will depend upon the country from which you will be mailing).

Please also send us a head shot of yourself that is in accordance with the requirements stated above so that it can be printed with your article.

Abstracts
An abstract of your article is not required.

Author or contact information
The author's contact information and a head shot of the author are included at the end of every article. Please note the exact information you would like to appear in this section and format it according to the requirements stated above. A short biographical sketch may precede the contact information if you provide us with the necessary information (60 words or less).

Questions?
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