Technical quality of root canal treatment and detection of iatrogenic errors in an undergraduate dental clinic

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Abstract

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Aim To evaluate the technical quality of root canal treatment (RCT) and detect iatrogenic errors in an undergraduate dental clinic.

Methodology Three-hundred and eighty-eight root-filled teeth from the records of the Department of Endodontology at the Aristotle University of Thessaloniki, Greece were evaluated. Evaluation of root-filled teeth was based on two variables: length and presence of voids within the root filling. The technical standard of root fillings was categorized as: ≤2 mm from the apex with no voids (acceptable); >2 mm from the apex with no voids; overfilling with no voids; ≤2 mm from the apex with voids; >2 mm from the apex with voids and overfilling with voids. Iatrogenic errors that were detected included ledges, root perforations, furcation perforations, strip perforations and presence of fractured instruments. Chi-squared analysis was used to determine statistically significant differences between frequencies of root fillings between each tooth type. Significant differences were also determined between frequencies of ledges and root perforations according to tooth type and separately in molars according to tooth number, canal location and root canal curvature.

Results Three-hundred and forty-three out of 620 root canals (55.3%) had a root filling that was classified as 'acceptable'. The frequency of root canals with an 'acceptable' filling was significantly greater in the anterior teeth (72.1%) than in pre-molars (55.2%) ($P < 005$) or in molars (46.7%) ($P < 0.001$). One-hundred and fifty-four (24.8%) root canals had ledges and 17 (2.7%) had a root perforation. The frequency of ledged root canals was significantly greater ($P < 0.001$) in molars than in anterior teeth. In molars, 105 out of 270 root canals (38.9%) had been ledged. Mesiobuccal, mesiolingual and distobuccal root canals were the most frequently ledged. Canal curvature was found to be the most important factor associated with ledges and root perforations.

Conclusions Technical quality was found to be acceptable more often in anterior teeth. Ledges were identified more often in curved canals in molar teeth.

Keywords: iatrogenic errors, root canal treatment, technical quality, undergraduate dental clinic.

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Introduction

Follow-up clinical studies have shown that root canal treatment (RCT) can achieve healing rates of 84% (Smith *et al.* 1993) to more than 90% (Sjögren *et al.* 1990). Each of these studies reported data from endodontic specialists and university clinics. These studies may be misleading in estimating the realistic outcome of endodontic treatment in general practice that approaches 60–75% (Eriksen *et al.* 2002). This discrepancy in outcome may reflect a difference in the technical quality of the RCT performed.

The prime objective of the root filling is to prevent reinfection and allow healing of the periapical tissues

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(Wesselink 2003). The importance of the technical quality of root filling in the prognosis of RCT has been extensively documented. Sjögren *et al.* (1990) and Smith *et al.* (1993) reported that the length of the root filling, relative to the radiographic apex, significantly affected the outcome of RCT with 87–94% healing rates associated with root fillings ending 0–2 mm from the radiographic apex. Lower healing rates were associated with 'short' root fillings ending more than 2 mm from the radiographic apex (68–77.6%) and with 'long' fillings extruding beyond the apex (75–76%). In addition, root fillings with a homogenous mass of filling material and with no voids are strongly correlated with a lower risk of disease (Chugal *et al.* 2003).

Recent endodontic epidemiological studies carried out in different population groups report a frequent finding of root fillings of inadequate quality (Table 1) and highlight the high prevalence of apical periodontitis in root-filled teeth.

It is also of particular importance to outline that the sequence of interdependent steps characteristic of RCT may be interrupted, or even fail, at any time or stage of the process due to iatrogenic complications. These procedural errors compromise canal cleaning and shaping, result in incomplete root filling and jeopardize the outcome of treatment (Lambrianidis 2001). Preparation outcomes such as ledges and root or strip perforations are possible results of canal transportation, which is defined as any undesirable deviation from the natural canal path. Canal transportation can result in inadequately cleaned canals with the possible outcome of persistent apical lesions (Peters 2004). Moreover, it has been shown that canal transportation is well correlated with leakage along root fillings (Wu *et al.* 2000). Perforations are also followed by infection of the periodontal ligament and the alveolar bone and consequently impair healing (Seltzer *et al.* 1970). Finally, correlation between instrument separation and negative clinical outcome has been discussed in detail (Crump & Natkin 1970).

There have been no published reports on the technical quality of root fillings in a Greek population. In addition, there are a few studies investigating the presence of specific iatrogenic errors (Greene & Krell 1990, Kapalas & Lambrianidis 2000). Such studies are necessary in order to assess the effectiveness of dental care and help with the planning of future dental training.

The purpose of this study was to determine the quality of root fillings and to identify the presence of ledges, root perforations, perforations of the lateral wall of the root (strip perforations), furcation perforations and fractured instruments, in cases treated in the Undergraduate Clinic of the Department of Endodontology at the Aristotle University of Thessaloniki, Greece.

Table 1 Epidemiological studies and percentages of adequate root fillings

Country	Study	Year	Number of root-filled teeth	% of adequate root fillings
Sweden	Petterson *et al.*	1986	650	38
Norway	Eriksen *et al.*	1988	133	40.5
Sweden	Ödesjö *et al.*	1990	1492	15.9
Switzerland	Imfeld	1991	406	36
The Netherlands	De Cleen *et al.*	1993	97	49.4
USA	Buckley & Spangberg	1995	291	42
Scotland	Saunders *et al.*	1997	472	38.6
Germany	Weiger *et al.*	1997	215	14
Portugal	Marques *et al.*	1998	69	46
Lithuania	Sidaravicius *et al.*	1999	586	12.5
Belgium	De Moor *et al.*	2000	312	40.7
Norway	Tronstad *et al.*	2000	1001	50,5
Denmark	Kirkevang *et al.*	2000	773	26.5
France	Boucher *et al.*	2002	1982*	20.8*
Belgium	Hommez *et al.*	2002	745	34.4
France	Lupi-Pegurier *et al.*	2002	1429	31.2
Poland	Boltacz-Rzepkowska & Pawlicka	2003	355	49
Canada	Dugas *et al.*	2003	383	38.9
Taiwan	Chueh *et al.*	2003	1085 1867**	30.3 34.8**
Jordan	Barrieshi-Nusair *et al.*	2004	542 912*	47.4*
Spain	Segura-Egea *et al.*	2004	93	34.4

*Roots.
**Root canals.

The hypotheses to be tested were:

1. Technical quality of root fillings is less frequently adequate in pre-molars and molars than in anterior teeth.
2. Ledges, root perforations and fractured instruments are more often associated with curved root canals.

Materials and methods

Selection of cases

The first 468 cases from a total of 895 cases, which were treated during two academic years (2001–2002, 2002–2003), were retrieved from the records of the Department of Endodontology at the Aristotle University of Thessaloniki, Greece and constituted the material used for this study. The cases were from patients referred within these two academic years to the Faculty of Dentistry of Aristotle University of Thessaloniki who had been treated by 4th and 5th year undergraduate students. Undergraduate students are able to treat endodontic cases including those with irreversible pulpitis, pulp necrosis, apical periodontitis and to perform intentional treatment of teeth with vital pulps as well as some cases of retreatment. More advanced cases, which require specialist treatment, such as teeth with perforations, fractured instruments, silver cones and posts are referred to the post-graduate clinic. One-hundred and thirty (130) undergraduate students were involved in the treatment of these cases. Supervision in the clinic was carried out with an academic staff:student ratio of 1:8. An aseptic technique with rubber dam isolation had been applied in all cases. Working length had been determined with the use of radiographs. All teeth had been instrumented with the stepback technique using K-files of 0.02 taper (Kerr Sybron, Romulus, MI, USA) and the canals had been irrigated with 2.5% NaOCl, whilst in some cases Gates-Glidden drills (Premier Dental, Norristown, PA, USA) had been used at the coronal third of the root canals in order to facilitate straight line access to the apical third. In cases where fine or calcified canals had to be negotiated, RC-Prep (Premier Dental Products, King of Prussia, PA, USA) had been used. Root fillings had been carried out with gutta-percha and Roth Root Canal Cement type 801 (Roth International Ltd, Chicago, IL, USA) using lateral condensation. Radiographs had been exposed using the bisecting-angle technique.

Evaluation of the technical quality of RCT and detection of the iatrogenic errors was based on the immediate postoperative radiograph of each case. In cases where a ledge was suspected, evaluation was also based on the working length and the master cone radiograph. Thirty-three (33) cases where final radiographs were missing or did not allow proper evaluation of any of the criteria of interest, due to poor radiographic technique or processing or overprojections of anatomical structures, were excluded from the study. In addition, 47 cases of endodontic retreatment were excluded, because of the possible presence of iatrogenic errors before retreatment. As a result, 388 cases were finally evaluated. These cases included 140 anterior teeth, 156 pre-molars and 92 molars.

Evaluation of the technical quality of root fillings and detection of iatrogenic errors

The two examiners defined strict criteria and were calibrated (Reit 1987) by discussing their application with a few selected cases which were not included in the study. Interexaminer agreement, as a part of the calibration procedure, was then determined by scoring 50 randomly selected postoperative radiographs in one round. These radiographs were included in the main study. In cases of disagreement, the two observers came to a consensus. An evaluation form was designed to record the information gathered from the immediate postoperative radiographs. The method of viewing the radiographs was standardized. Radiographs were interpreted in a darkened room using an illuminated viewer box (Dentsply Rinn Corp. Elgin, IL, USA) with magnification (4×) whilst mounted in a cardboard slit to block off ambient light emanating from the viewer. Measurements were recorded using a transparent ruler of 0.5 mm accuracy.

The technical quality of the root fillings and the presence of iatrogenic errors depicted on radiographs were evaluated and classified. The recorded data included tooth type, length and presence of voids of root filling and presence of a ledge, root perforation, strip perforation, furcation perforation and fractured instrument in each root canal that was examined. Multicanal teeth with superimposed canal fillings recorded in the final radiograph, were assessed according to the radiographic image which was visible for only one root canal filling. In cases of radiographs from maxillary pre-molars and mandibular molars, which had been exposed with alteration in horizontal angulation by the students, it was always considered that they had been exposed with a mesial angulation. As a result, according to the buccal object rule, it was possible to differentiate the palatal from the buccal root

canal in maxillary pre-molars and the mesiobuccal from the mesiolingual root canal in mandibular molars. Thus, the root canals that were depicted distally on radiographs were the buccal root canal in maxillary pre-molars and the mesiobuccal root canal in mandibular molars.

The criteria for the radiographic classification were as follows:

Quality of root fillings:

- A length of ≤2 mm from the apex with no voids ('Acceptable' filling): filling ending 0–2 mm short of the apex with uniform radiodensity and adaptation of the filling to the root canal walls.
- Overfilling with no voids: filling extruding beyond the apex with uniform radiodensity and adaptation of the filling to the root canal walls.
- A length of >2 mm from the apex with no voids: filling ending more than 2 mm from the radiographic apex with uniform radiodensity and adaptation of the filling to the root canal walls.
- A length of ≤2 mm from the apex with voids: filling ending 0–2-mm short of the apex with visible canal space laterally along the filling or voids within the filling mass.
- Overfilling with voids: filling extruding beyond the apex with visible canal space laterally along the filling or voids within the filling mass.
- A length of >2 mm from the apex with voids: filling ending more than 2 mm from the radiographic apex with visible canal space laterally along the filling or voids within the filling mass.

Detection of iatrogenic errors:

- Ledge formation was diagnosed when the root filling was at least 1 mm shorter than the initial working length or deviated from the original canal shape in teeth where root canal curvature occurred.
- Furcation perforation was diagnosed when extrusion of filling material through the furcation area was detected in multi-rooted teeth.
- Strip perforation was diagnosed when extrusion of filling material was detected in the lateral (inner) wall of mesiobuccal roots of maxillary molars, mesial roots of mandibular molars and in any root of other teeth.
- Root perforation was diagnosed when extrusion of filling material was detected in any other area of a root except the furcation area and the lateral wall of the root.
- Presence of a fractured instrument was diagnosed when a fractured instrument was detected inside a root canal or with its tip extending into the periapical area.

The clinical parameters under consideration for the iatrogenic errors were tooth number, canal location, root canal curvature and the position (coronal, middle or apical third) inside the root canal. Degree of root canal curvature was determined by the technique of Schneider (1971). The canals were classified according to the degree of their curvature as straight (<5°), moderate (<20°) and severe (>25°).

Statistical analysis

Interexaminer agreement was measured by Cohen's kappa (k) values (Hunt 1986, Valachovic *et al.* 1986). Because of the good interobserver k-values, the scores of one author (GE) were used for evaluation of the radiographic findings of the 388 cases that were included in the study. The k-statistic was also used to assess the intraobserver agreement of each examiner, which was determined by rescoring 50 randomly selected final radiographs at least 2 months after the original examination. SPSS 11.0 for Windows software (SPSS Inc., Chicago, IL, USA) was used for data processing and statistical analysis. The chi-squared statistic was used for statistical evaluation of the results. A P-value < 0.05 was considered statistically significant.

Results

Calibration procedure

The k-value for interexaminer variability was 0.85 for 'length of root filling' and 0.72 for 'presence of voids'. The k-values for intraexaminer reproducibility were 0.83 for 'length of root filling' and 0.79 for 'presence of voids'.

Technical quality of root fillings

Root filling length was adequate in 389 of the 620 root canals that were evaluated (62.7%). No voids were present in 512 (82.6%) root canals.

'Acceptable' filling defined as having both adequate filling length and no voids was found in 343 (55.3%) root canals. Of the 343 root canals, 101 were from anterior teeth, 116 from pre-molars and 126 from molars. Fillings ending >2 mm from the apex with no voids were found in 134 (21.6%) root canals and overfilling with no voids was found in 35 (5.6%) root canals. Fillings ending ≤2 mm from the apex with voids were found in 46 (7.4%) root canals, fillings ending

Table 2 Percentages of root canals with acceptable fillings according to tooth types

Tooth types	Root canal with 'acceptable' fillings	Number of root canals	Percentage
Anterior teeth	101	140	72.1[a, b]
Pre-molars	116	210	55.2
Molars	126	270	46.7
Total	343	620	55.3

[a]Statistically significant difference ($P < 0.05$) between anterior and pre-molar teeth.
[b]Statistically significant difference ($P < 0.001$) between anterior and molar teeth.

>2 mm from the apex with voids in 51 (8.2%) root canals and overfilling with voids was found in 11 (1.8%) root canals. A significant difference in the frequency of root canals with 'acceptable' fillings was found between anterior teeth and pre-molars ($P < 0.05$) and between anterior teeth and molars ($P < 0.001$). However, there was no significant difference in the frequency of root canals with 'acceptable' fillings between pre-molars and molars (Table 2).

Iatrogenic errors

Ledges were found in 154 of the 620 root canals (24.8%). A significant difference in the frequency of ledged root canals was found between anterior teeth and molars ($P < 0.001$) and between pre-molars and molars ($P < 0.001$). There was no significant difference in the frequency of ledged root canals between anterior teeth and pre-molars (Table 3).

The location of anterior teeth and pre-molars and the canal location in pre-molars were not statistically significant variables.

The second left mandibular molar exhibited the highest incidence (62.5%) of ledged root canals in molars. The second left maxillary molar was ledged in 52.2% of cases. The location of molars was not a statistically significant variable at $P < 0.05$ ($\chi^2 = 12.027$, d.f. $= 7$, $P = 0.100$).

Table 3 Percentages of ledged root canals according to tooth types

Tooth types	Ledged root canals	Number of root canals	Percentage
Anterior teeth	16	140	11.4[a]
Pre-molars	33	210	15.7[b]
Molars	105	270	38.9
Total	154	620	24.8

[a]Statistically significant difference ($P < 0.001$) between anterior and molar teeth.
[b]Statistically significant difference ($P < 0.001$) between pre-molar and molar teeth.

Table 4 Pearson's test for ledged root canals in molars according to canal location

Comparison	χ^2	d.f.	*P*-value
Mesiobuccal vs. mesiolingual	0.979	1	0.322
Mesiobuccal vs. distal	12.468	1	0.000*
Mesiobuccal vs. distal buccal	1.387	1	0.239
Mesiobuccal vs. palatal	8.647	1	0.003*
Mesiolingual vs. distal	16.611	1	0.000*
Mesiolingual vs. distal buccal	3.489	1	0.062
Mesiolingual vs. palatal	12.145	1	0.000*
Distal vs. distal buccal	3.397	1	0.065
Distal vs. palatal	0.002	1	0.967
Distal buccal vs. palatal	2.520	1	0.112

*Significant at 95%.

Canal location in molars had an effect on the incidence of ledging as the mesiobuccal canal in maxillary and mandibular molars, mesiolingual canal in mandibular molars and distobuccal canal in maxillary molars were ledged more frequently than the distal canal in mandibular molars and palatal canal in maxillary molars. The differences were statistically significant between mesiobuccal and distal, mesiobuccal and palatal, mesiolingual and distal and between mesiolingual and palatal root canals (Table 4).

In respect to canal curvature, ledges in all teeth were found in 5.9% of straight canals, in 40.4% of moderately curved canals and in 58.4% of severely curved canals. A significant difference was found between straight and moderately curved canals ($P < 0.001$), straight and severely curved canals ($P < 0.001$) and between moderately and severely curved canals ($P < 0.05$) (Table 5).

Table 5 Percentages of ledged root canals in all teeth according to canal curvature

Curvature	Ledged root canals	Number of root canals	Percentage
Straight	19	320	5.9[a, b]
Moderate	90	223	40.4[c]
Severe	45	77	58.4
Total	154	620	24.8

[a]Statistically significant difference ($P < 0.001$) between canals with straight and moderate curvature.
[b]Statistically significant difference ($P < 0.001$) between canals with straight and severe curvature.
[c]Statistically significant difference ($P < 0.05$) between canals with moderate and severe curvature.

Table 6 Percentages of ledged root canals in molars according to canal curvature

Curvature	Ledged root canals	Number of root canals	Percentage
Straight	11	72	15.3[a, b]
Moderate	69	157	43.9
Severe	25	41	61
Total	105	270	38.9

[a]Statistically significant difference ($P < 0.001$) between canals with straight and moderate curvature.
[b]Statistically significant difference ($P < 0.001$) between canals with straight and severe curvature.

Table 7 Percentages of root canals with perforation in all teeth according to canal curvature

Curvature	Root canals with perforation	Number of root canals	Percentage
Straight	0	320	0[a, b]
Moderate	11	223	4.9
Severe	6	77	7.8
Total	17	620	2.7

[a]Statistically significant difference ($P < 0.001$) between canals with straight and moderate curvature.
[b]Statistically significant difference ($P < 0.001$) between canals with straight and severe curvature.

In molars, ledges were found in 15.3% of straight canals, in 43.9% of moderately curved canals and in 61% of severely curved canals. A significant difference was found between straight and moderately curved canals ($P < 0.001$) and between straight and severely curved canals ($P < 0.001$) (Table 6). The difference between moderately and severely curved root canals did not reach significance ($\chi^2 = 3.780$, d.f. $= 1$, $P = 0.052$).

Canal curvature was the most significant factor affecting the incidence of ledging in all teeth and in molars.

Root perforation was detected in 17 of the 620 root canals (2.7%). Canal curvature was the only statistically significant factor and a significant difference was found between straight and moderately curved canals ($P < 0.001$) and between straight and severely curved canals ($P < 0.001$) (Table 7).

In molars, canal curvature had the strongest correlation with the presence of root perforations.

Strip and furcation perforations were each detected in one case and a fractured instrument was present in two root canals.

Discussion

Evaluation of technical quality was based on the image of the root filling on the immediate postoperative radiograph of each case. However, endodontic radiographic interpretation imposes some limitations because a single radiograph provides only a two-dimensional image. Therefore, it is not possible to separate superimposed anatomical structures, such as the root canals. In addition, length of the roots and canal fillings may not be reproduced accurately. Especially in the region of maxillary molars, overprojection of anatomical structures (maxillary antrum, zygomatic bone, zygomatic process of the maxilla) may contribute to difficulties in radiographic interpretation (Tamse *et al.* 1980, Lambrianidis 1985). Because of the possibility of radiographic misinterpretation due to these limitations, an effort was made to exclude most of the radiographs with superimposed canal fillings or overprojections of anatomical structures.

Previous epidemiological studies have used different criteria when categorizing root fillings as adequate or inadequate. Some studies have concentrated merely on the length of the root fillings (De Cleen *et al.* 1993, Saunders *et al.* 1997, De Moor *et al.* 2000), whilst most of the studies used both length and lateral adaptation of root fillings (Petterson *et al.* 1986, Eriksen *et al.* 1988, Ödesjö *et al.* 1990, Imfeld 1991, Buckley & Spangberg 1995, Weiger *et al.* 1997, Marques *et al.* 1998, Sidaravicius *et al.* 1999, Kirkevang *et al.* 2000, Tronstad *et al.* 2000, Boucher *et al.* 2002, Hommez *et al.* 2002, Lupi-Pegurier *et al.* 2002, Boltacz-Rzepkowska & Pawlicka 2003, Chueh *et al.* 2003, Dugas *et al.* 2003, Barrieshi-Nusair *et al.* 2004, Segura-Egea *et al.* 2004). In addition, most of the studies considered the apical termination of the root filling ≤2 mm from radiographic apex as the gold standard, whilst others used a broader standard of ≤3 mm from the radiographic apex as a criterion for an adequate root filling (Marques *et al.* 1998, Sidaravicius *et al.* 1999, Kirkevang *et al.* 2000, Segura-Egea *et al.* 2004).

When studies included the lateral adaptation of the root filling as a criterion, there was general agreement that if a void was present between the filling and the canal walls, the filling should be categorized as inadequate. However, limited reproducibility of the adaptation of the filling to the root canal walls has been demonstrated in several studies (Reit & Hollender 1983, Lambrianidis 1985, Eckerbom *et al.* 1986, Kersten *et al.* 1987, Eckerbom & Magnusson 1997). Eckerbom & Magnusson (1997) demonstrated that the

reliability of one orthoradial radiograph was poor when evaluating the adaptation of the filling to the root canal walls. This should be evaluated in images with a mesial and/or distal angulation to get a realistic estimate of the quality of the filling (Kersten *et al.* 1987, Eckerbom & Magnusson 1997, Kirkevang & Horsted-Bindslev 2002).

The length of the root filling is a much more reproducible quality parameter than the lateral adaptation, probably because it is easier to measure the length of the root filling than it is to detect voids (Eckerbom & Magnusson 1997, Kirkevang & Horsted-Bindslev 2002). The apical limit of the root filling has been a topic for discussion for decades, but most studies indicate that the apical limit should be placed at the apical constriction of the root canal. In the present study, 62.7% of the root canals were considered to have adequate root filling length. However, estimation of the filling length was probably not reproduced correctly in all radiographs because postoperative radiographs had been exposed by the undergraduate students using the bisecting-angle technique. Forsberg (1987) demonstrated that root fillings are projected shorter, i.e. more coronally on the radiographs exposed with the bisecting-angle technique than with the paralleling technique.

Estimating only the number of root canals with adequate lateral seal or only the number of root canals with adequate root filling length has limited clinical value. Only the estimation of the number of root canals with 'acceptable' fillings is important for the outcome of RCT and can give a more comprehensive image of the overall technical quality.

The two examiners were calibrated before the start of the study in order to minimize interobserver and intraobserver variability. Studies have demonstrated great variations amongst observers in respect to evaluation of technical quality of root fillings (Reit & Hollender 1983, Lambrianidis 1985). The *k*-values of 0.85 and 0.72 in the ratings of 'length of root filling' and 'presence of voids' indicate excellent agreement between the observers. To measure the intra-examiner reliability, the values of agreement were greater than 0.78, indicating high consistency of each examiner. All these values were due to thorough calibration of the investigators and the well defined criteria used.

The frequency of root canals with an 'acceptable' filling (55.3%) was higher than the results of previous studies (Table 1). However, it is difficult to compare the studies due to the different criteria that were used. This frequency was also higher than the 47.4% reported by Barrieshi-Nusair *et al.* (2004) and much higher than the 13% reported by Hayes *et al.* (2001), who evaluated treatments performed by undergraduate students.

Whilst the technical quality of root fillings as illustrated by radiographs is important for the outcome of the treatment, it may not reflect the quality of the treatment in general. The antiseptic and aseptic efforts during treatment, quality of canal preparation, materials used and treatment routines including antibacterial regimen are amongst many prognostic factors that remain unknown from epidemiological studies (Eriksen *et al.* 2002). The major factor associated with endodontic failure, even in well-treated teeth, is the persistence of microbial infection in the root canal system (Nair *et al.* 1990, Lin *et al.* 1992, Siqueira 2001). In cases of infected root canals, complete radiographic periapical healing occurs in 94% of the cases that yield a negative culture before obturation, whilst in cases of positive culture success rate of treatment occurs in just 68% of the cases (Sjögren *et al.* 1997). Despite the fact that the use of rubber dam was compulsory in the undergraduate dental clinic, further care must be taken in order to avoid persistence or introduction of microorganisms into the root canal system during all stages of RCT.

All iatrogenic errors cannot be depicted on radiographs. Overinstrumentation, for example, which may push pulp remnants and microorgranisms beyond the apex causing acute apical periodontitis, can be detected by the use of radiographs only when it is followed by extrusion of filling material, but not during previous stages of RCT (Lambrianidis 2001).

The results indicated that 24.8% of all root canals had ledges. Anterior teeth and pre-molars were ledged less frequently than molars. This probably occurred due to the prevalence of narrow and curved root canals in molars. Preparation of curved root canals creates a challenge due to the problem of canal straightening by the inherent restoring forces of the file design and alloy. Straightening of the canal occurs principally at the outer wall of the apical portion of the canal (Weine *et al.* 1975).

In molars, a ledge was present in 38.9% of the root canals. This percentage is lower than that reported by Greene & Krell (1990) (46%) and than that reported by Kapalas & Lambrianidis (2000) (51.5%). Both these studies, using the same criteria as the present study, detected the presence of ledges in treatments performed by undergraduate students. Canal curvature was found to be the most significant factor affecting the incidence of ledging. As canal curvature increased, the number of

ledges also increased. This is in complete agreement with previous findings of Greene & Krell (1990) and Kapalas & Lambrianidis (2000).

In the present study a ledge was considered to be present when the root filling was at least 1 mm shorter than the working length or deviated from the original canal curvature. However, a 'short' filling may also be due to packed dentinal chips or residual debris which are forced periapically during instrumentation, resulting in apical canal blockage. The stepback technique, which had been used by the undergraduate students, has been shown to induce such clinical complications and consequently may have attributed to increased ledge incidence rates.

Concerning the presence of root perforations, canal curvature showed the strongest correlation. Strip perforation was associated with the use of Gates-Glidden drills. When these drills are used with a clockwise rotation, they are sometimes wedged in dentine and the motion pushes them apically, thus increasing the risk of a perforation (Lambrianidis 2001).

The small number of root perforations may have had a negative effect on detecting statistically significant differences. The small number of root, strip and furcation perforations and fractured instruments can be explained by the fact that any error occurring in the undergraduate clinic is referred to the post-graduate clinic. As a result patient files from these cases are missing from the undergraduate records of the Department of Endodontology.

Important adjuncts in modern endodontic treatment, such as nickel–titanium rotary instruments and electronic apex locators were not used during the treatment of the cases that were included in this study. It has been demonstrated that Ni–Ti rotary instruments shape the root canal better than conventional instruments with fewer procedural errors (Park 2001). Furthermore, electronic apex locators are claimed to be more reliable than radiographs to identify the working length of the root canal (Pratten & McDonald 1996). Therefore, their use could have been beneficial in minimizing the risk of procedural errors. Finally, the use of patency files has been proposed to prevent the occurrence of preparation errors. However, this concept was not used during the treatment of the cases that were evaluated.

Conclusions

The quality of RCT performed by undergraduate dental students was classified as 'acceptable' in more than 50% of cases. Technical quality was more often adequate in anterior teeth than in pre-molars and molars. Canal curvature was the most important clinical factor associated with ledge formation and presence of root perforations.

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