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The technical quality of nonsurgical root canal treatment performed by a selected cohort of Australian endodontists

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Abstract

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Aim To investigate the technical quality of nonsurgical root canal treatment performed by endodontists in Melbourne, Australia.

Methodology Clinical and radiographic records of 100 sequential nonsurgical patients were obtained from each of six endodontists working in private practice. The following variables were analysed: proximity of root filling to radiographic apex; homogeneity and radiodensity of root filling; lateral adaptation of the root filling to the canal walls; taper; extrusion of material; small, appropriate or excessive apical enlargement; presence of lateral canals; transportation; procedural errors. The radiographs were assessed by three independent evaluators. Exploratory data analysis was undertaken using simple frequencies and cross-tabulations. A generalised linear mixed model (GLMM) was used for the formal statistical modelling.

Results Of the 1351 canals that were examined, 91.7% were filled within 2 mm of the radiographic apex and 74% were within 1 mm. Homogeneity and adequate density were found along the entire length of the canal in 86.1% and 88.6% of cases respectively. Lateral adaptation was adequate in 95.6% of cases and the taper was 'smooth and continuous' in 83.8% of roots. No and/or small extrusion of sealer was noted in 98.3% of cases. Apical enlargement was 'appropriate' in 85% of roots. Both transportation (1.1%) and procedural errors (1.3%) were rare occurrences.

Conclusions The technical quality of root fillings performed by endodontists in Melbourne, Australia complied with current guidelines in 77.4%–91.0% of roots. All variables examined confirmed high levels of technical proficiency. There were very few instances of canal transportation and/or procedural errors.

Keywords: Australia, endodontics, radiographic interpretation, root canal treatment, specialist, technical quality.

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Introduction

The technical quality of root fillings in relation to prognosis of root canal treatment has been extensively researched. Cross-sectional studies describe the relationship between diseases (or other health-related states) and other factors of interest, as they exist in a specified population at a particular time. They are able to measure the frequency (prevalence) of conditions and demonstrate associations. As compared to longitudinal studies, cross-sectional studies suggest a high frequency of inadequate root fillings performed by general dentists as well as a high rate of apical periodontitis associated with root-filled teeth (Ödesjö *et al.* 1990, Buckley & Spångberg 1995, Weiger *et al.* 1997, Sidaravicius *et al.* 1999, De Moor *et al.* 2000, Kirkevang *et al.* 2000, Chen *et al.* 2007). This has also been found for treatment performed by endodontists (as reported by patients), where an adequate root filling

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was found in only 51.4% of cases (Dugas *et al.* 2003). It would therefore appear that the general and specialist dental professions may not be able to achieve an adequate technical standard of root filling in a consistent reliable manner. These studies also correlate the quality of root fillings with periapical status and report a high prevalence of apical periodontitis related to endodontically treated teeth.

The definition of 'quality' in root canal filling differs amongst investigators, with some examining only the length of the filling relative to the radiographic apex (Friedman *et al.* 1995, Dammaschke *et al.* 2003), and others assessing the quality of the root filling as reflected by the density of the root filling (Sjögren *et al.* 1990, Buckley & Spångberg 1995, Segura-Egea *et al.* 2004). When the technical standard of root canal treatment was deemed to be adequate, healing rates between 70 and 100% were found (Kirkevang & Hörsted-Bindslev 2002). However, healing rates diminish substantially to between 50 and 90% for cases that have been overfilled (i.e. beyond the radiographic apex). Further, if the root filling was deemed to be short of the radiographic apex, healing rates of 57%–95% were found. The definitions of adequate and inadequate technical standards differ amongst studies and therefore comparisons between studies are difficult (Kirkevang & Hörsted-Bindslev 2002).

The correlation between density of the root filling and prognosis is less clear than proximity of the root filling to the radiographic apex. Some studies (Ödesjö *et al.* 1990, Sjögren *et al.* 1990, Marques *et al.* 1998, Sidaravicius *et al.* 1999) have reported no difference in prognosis between adequately and inadequately compacted root fillings. Other studies (Strindberg 1956, Kerekes & Tronstad 1979, Chugal *et al.* 2003, Dugas *et al.* 2003, Stoll *et al.* 2005) have found that a root filling that is less dense and nonhomogenous will have a negative impact on outcome. These longitudinal studies have generally been undertaken in controlled environments at dental schools or specialist clinics. Despite the different methodologies, these studies suggest that when the technical quality of root fillings is undertaken at a high level, it is possible to control and eliminate apical periodontitis (Kirkevang & Hörsted-Bindslev 2002).

With the advent of rotary nickel–titanium (NiTi) instruments and the use of the operating microscope, the methods with which clinicians, particularly endodontists, instrument and fill root canal systems has changed. Molander *et al.* (2007) have shown that replacing stainless steel instruments with rotary NiTi instrumentation increases the rate of good quality root fillings. Hence, the earlier studies looking at the technical standard of root fillings may not be relevant to today's standards. Additionally, the technical standard of root fillings using this new technology has not been widely researched. The only case–controlled study analysing contemporary techniques (Spili *et al.* 2005) reported largely on fractured instruments and therefore did not allow for a large number of cases to be scrutinized. However, they did report an overall success rate for cases and controls of 93.7%.

Therefore, the purpose of this study was to examine, using clinical and radiographic records, the technical standard of root fillings undertaken by specialist endodontists in Melbourne, Australia performed using new rotary NiTi techniques.

Materials and methods

Study design

This was a retrospective study of 600 cases treated nonsurgically (including re-treatment) by six endodontists in three private specialist endodontic practices in Melbourne, Australia. The endodontists had between 4 and 26 years of experience in specialist practice. Three endodontists had completed their postgraduate degree within the past 10 years and had trained with rotary NiTi instruments. The remaining three endodontists had been in specialist practice for more than 15 years, and their training preceded rotary NiTi instruments. All of the endodontists routinely used rotary NiTi instruments with primarily a 'crown-down' technique. Additionally, cold lateral compaction was the primary filling technique. The cases selected were the most recent 100 root fillings performed by the individual endodontists in 2005. In the instance where another tooth from the same patient was seen at a later date, this tooth was also included in the study. Ethical approval for the project was obtained from the University of Melbourne Human Research Ethics Committee. All patient records included for analysis were de-identified through a suitable code that maintained their anonymity throughout the study. All relevant clinical and radiographic data were coded and entered in Excel® spreadsheets (Microsoft Corporation, Redmond, WA, USA).

Clinical examination

The principal author analysed each patient's record for the following variables: (i) tooth type, whether the tooth was previously accessed by the referring dentist,

(ii) type of treatment required (nonsurgical primary treatment or re-treatment), (iii) iatrogenic or procedural problems, (iv) apical enlargement size, (v) number of visits (not including consultation), (vi) irrigants, (vii) intracanal medicament(s).

All of the above information was collected via the clinical records that were attached to the patient's file including any written correspondence between the referring dentist and the endodontist.

Radiographic examination

All relevant radiographs were scanned using an 8-bit greyscale at 400 dpi (Epson Perfection V700 Photo scanner, Seiko Epson Corporation, Nagano, Japan). The scale was maintained at 100%, and all radiographs were saved in JPEG format under a code for both the patient and the operator.

The radiographs were analysed for the seven variables shown in Table 1 using the indicated categories. As noted in the clinical records, technical standard was analysed solely on the filling of canals with gutta-percha and sealer. Any cases that were filled with an alternative material (i.e. Mineral Trioxide Aggregate) were excluded.

Three different endodontists who had not treated any of the examined cases were calibrated and subsequently evaluated all coded radiographs blindly. Viewing was performed in a darkened room with the scanned images projected onto a screen. The examiners were situated 2 m from the screen. The viewing of the radiographs was completed using Adobe Photoshop CS2 9.0.2 (Adobe Systems Incorporated, San Jose, CA, USA). The unit of radiographic evaluation was the individual root.

When there was no filling material found in a specific area of the canal because of the presence of a post, a recording of 'not applicable' was made. Similarly, when there was no filling material in the apical third of the canal (i.e. the clinician was unable to negotiate the apical third of the canal), a recording of 'not applicable' was made for density, taper, apical enlargement and transportation.

Calibration of examiners

Each examiner was individually calibrated for all the factors listed in Table 2 by rating 35 random sample cases that were not part of the study.

The radiographic assessment of the 600 cases was completed independently by the three endodontists in blocks of 30 cases. Following the assessment of 30 cases, the results were collated and any disagreement between the examiners was resolved by reaching a consensus. Proximity of the root filling relative to the radiographic apex was quantified by the principal author using the measuring tool included in the Photoshop CS2 package. A reading to 0.1 mm was recorded.

Outcome assessment–assessment of adequate endodontic treatment

In addition to scoring individual variables as listed in Table 1, results were dichotomised to rate each root as 'adequate' or 'inadequate' technical standard. The outcome assessment was based on the study undertaken by Molander *et al.* (2007), except that the

Table 1 Radiographic analysis

Density[a]	Taper[b]	Lateral adaptation[c]	Extrusion (Sealer)[d]	Lateral canals	Apical enlargement[e]	Transportation[f]
Homogenous	Smooth and continuous	Adequate	None	Number	Small	None
Non homogenous	Irregular	Inadequate	Small		Appropriate	Moderate
Adequate	Excessive		Large		Excessive	Severe
Low	Absent					

[a]For the statistical analysis, this variable was divided into variable 1 (homogenous versus non-homogenous) and variable 2 (adequate versus low). Variable 1 was based on the uniformity of the root filling density. Variable 2 was based on the radiodensity of the root filling.
[b]Taper was based on the contours of the root filling measured from radiographic apex to its coronal extent.
[c]No lumen lateral to the root filling.
[d]No and/or small extrusion of sealer only was deemed adequate. Large sealer extrusion was assigned when its diameter ≥ 2 mm.
[e]The apical 1–2 mm of the root filling was assessed and the extent of enlargement was assigned based on its dimension relative to the root morphology.
[f]No transportation – The root filling followed the natural contour of the root filling.
Moderate/severe transportation – The root filling tended to straighten relative to the natural contour of the root outline.

Table 2 Patient and treatment characteristics (frequency tables)

	Frequency	%
Type of tooth		
Anterior	117	20.2
Premolar	104	18.0
Molar	357	61.8
Total	578	100.0
Mandibular anterior	26	1.9
Mandibular premolar	42	3.1
Mandibular molar	643	47.6
Maxillary anterior	94	7.0
Maxillary premolar	96	7.1
Maxillary molar	450	33.3
Total	1351	100.0
Previous treatment		
Initial	469	81.1
Re-treatment	109	18.9
Total	578	100.0
Previous access		
Referring dentist	283	49.7
Endodontist	286	50.3
Total	569[a]	100.0
Number of appointments		
1	27	4.7
2	443	76.8
3	101	17.5
4	6	1.0
Total	577[b]	100.0

[a]Nine cases were unknown due to the information not being recorded.
[b]One case was unknown due to the information not being recorded.

maximum acceptable length was 2.0 mm rather than 2.5 mm.

Outcome assessment (based on Molander et al. 2007)
Definition 1. Correct length (within 2 mm of radiographic apex), adequate lateral adaptation of the root filling to the canal walls, smooth and continuous taper, and no transportation.

Definition 2. Correct length (within 2 mm of radiographic apex), adequate lateral adaptation of the root filling to the canal walls, lack of taper and/or transportation.

Statistical analysis

Exploratory data analysis
The descriptive statistics consisted of simple frequencies and cross-tabulations. Cross-tabulations display the distribution of responses of one categorical variable across levels of another categorical variable.

Formal statistical modelling
The statistical technique most appropriate for assessing associations between sets of variables depends on the nature of the outcome variable. With the exception of apical enlargement size, which was a continuous variable, all outcomes of interest in this data set were categorical. Some of the categorical outcome variables were binary (i.e. only two categories) such as lateral adaptation of the root filling, some were ordinal (i.e. more than two categories where the categories have a natural order) such as extrusion and some were nominal (i.e. more than two categories where the categories have no natural order to them) such as taper.

All of the outcome variables related to specific aspects of the treatment applied and were therefore measured at the lowest level of variation, the canal. The set of explanatory variables was measured at different levels of variation. A list of all the explanatory variables measured at each level of variation follows:

Level of variation	Variable
Operator	- Operator
Patient/tooth	- Tooth location
	- Tooth type
	- Previous treatment
	- Previous access
	- Appointment
Canal level	- Type of canal

For binary response variables, the statistical technique used was a generalised linear mixed model (GLMM). The following approach to analysis was undertaken:

1. A GLMM analysis of each binary outcome variable in the data set.
2. All categorical outcome variables with more than two levels were made into binary variables by combining some of the original categories. A GLMM analysis was then performed on the newly formed binary variables.
3. The only continuous outcome variable in the data set was the analysis of apical enlargement. This was analysed by fitting a Residual Maximum Likelihood (REML) mixed model. This accounted for multiple levels of variation in the data and therefore assessed the statistical significance of the explanatory variables appropriately.

The statistical package GenStat (VSN International, Hempstead, UK) was used for all statistical analysis.

GLMM analysis for categorical outcome variables
The GLMM analysis indicated that some of the variables had very few observations in one of the two categories. Therefore, because very little reliable information would be gained from such an analysis, it was decided not to proceed with a GLMM analysis for the following variables:

- Density middle (variable 2: adequate/low)
- Density coronal (variable 1: homogenous/nonhomogenous)
- Density coronal (variable 2: adequate/low)
- Lateral canal
- Transportation
- Procedural errors

Results

Patient and treatment characteristics

The final data set consisted of 578 teeth with a total of 1351 roots. Table 2 lists the relevant findings.

Technical standard
There were 1351 separate assessments of root fillings on canals in the data set. Overall, a high percentage of roots was found to have a root filling that was homogenous (86.1%) and with adequate density (88.6%) in the apical, middle and coronal sections of the root canal (Table 3). Of the 1351 canals, 83.8% had a 'smooth and continuous taper', 9% were 'irregular' and 7.3% had no discernible taper. An adequate lateral adaptation of the root filling occurred in 95.6% of the canals, and the absence (67.1%), or a minor (31.2%) extrusion of sealer was noted in 98.3% of canals. Apical enlargement was 'appropriate' in 85% of cases, 'small' in 12.5% and 'excessive' in only 2.0%. Transportation (1.2%) and the presence of a lateral canal (3.8%) were rarely noted. Very few procedural errors (1.3%) were identified, and these included perforations, fractured instruments and ledged canals.

Length
Table 4 shows the proximity of the root filling relative to the radiographic apex. A statistically significant difference was found between operators ($P = 0.01$). The highest percentage of teeth with root fillings ending within 1 mm of the radiographic apex occurred for mandibular anteriors (88.4%) followed by maxillary anteriors (78.7%). The significant differences were as follows, with the underlined tooth type having the root filling terminate closer to the radiographic apex:

Table 3 Density (frequency)

Variable	Assessment	Frequency	%
Density A	Homogenous	1135	84
	Non-homogenous	201	14.9
	Not assessed	15	1.1
	Total	1351	100
	Adequate	1186	87.8
	Low	150	11.1
	Not assessed	15	1.1
	Total	1351	100
Density M	Homogenous	1191	88.2
	Non-homogenous	65	4.8
	Not assessed	95	7
	Total	1351	100
	Adequate	1230	91
	Low	26	1.9
	Not assessed	95	7
	Total	1351	100
Density C	Homogenous	1162	86
	Non-homogenous	20	1.5
	Not assessed	169	12.5
	Total	1351	100
	Adequate	1177	87.1
	Low	5	0.4
	Not assessed	169	12.5
	Total	1351	100

1. Mandibular anteriors and mandibular molars (Odds Ratio (OR) 0.20, 95% confidence interval (CI) 0.07, 0.55), maxillary anteriors (OR 0.26, 95% CI 0.08, 0.78), maxillary molars (OR 0.32, 95% CI 0.11, 0.91) and maxillary premolars (OR 0.22, 95% CI 0.07, 0.69).
2. Mandibular molars and maxillary molars (OR 1.64, 95% CI 1.13, 2.36)

Teeth that had been previously accessed were found to have root fillings that terminated closer to the radiographic apex ($P = 0.02$).

Density
Apical density. A statistically significant difference was found between operators for both variable 1 (homogenous/nonhomogenous) ($P < 0.001$) and variable 2 (adequate/low) ($P < 0.001$).

Middle density. A statistically significant difference was found between operators ($P = 0.05$). Additionally, teeth that had been previously accessed were found to have a higher density ($P = 0.02$) for variable 1 (homogenous/nonhomogenous).

Lateral adaptation of the root filling to the canal walls
There was minimal variation of lateral adaptation of the root filling according to the tooth type. Adequacy of

Table 4 Proximity of the root filling relative to the radiographic apex (frequency)

	Length								
Tooth	Less than −2.0 mm[a]	−2.0 to −1.6 mm	−1.5 to −1.1 mm	−1.0 to −0.6 mm	−0.5 to −0.1 mm	0 mm	0.1 to 0.5 mm	Greater than 0.5 mm	Total
Mandibular anterior									
Count	1	1	1	5	1	17	0	0	26
Row %	3.8	3.8	3.8	19.2	3.8	65.4	0.0	0.0	100.0
Mandibular molar									
Count	33	51	72	230	61	168	22	6	643
Row %	5.1	7.9	11.2	35.8	9.5	26.1	3.4	0.9	100.0
Mandibular premolar									
Count	2	5	4	10	7	13	1	0	42
Row %	4.8	11.9	9.5	23.8	16.7	31.0	2.4	0.0	100.0
Maxillary anterior									
Count	6	4	6	35	6	33	1	3	94
Row %	6.4	4.3	6.4	37.2	6.4	35.1	1.1	3.2	100.0
Maxillary molar									
Count	17	30	48	119	52	172	6	6	450
Row %	3.8	6.7	10.7	26.4	11.5	38.3	1.3	1.3	100.0
Maxillary premolar									
Count	2	8	10	31	12	27	3	3	96
Row %	2.1	8.3	10.4	32.3	12.5	28.1	3.1	3.1	100.0
Total									
Count	61	99	141	430	139	430	33	18	1351
Row %	4.5	7.3	10.4	31.9	10.3	31.9	2.4	1.3	100.0

[a]Minus sign indicates root filling is short of the radiographic apex.

lateral adaptation ranged between 92.7% for maxillary premolars and 97.6% for mandibular premolars. No statistically significant differences were found in this group.

Taper

The highest percentage of root fillings having a 'smooth and continuous' taper was seen in the mandibular molars (88.5%). A statistically significant difference was found amongst the operators ($P < 0.001$). Additionally, with reference to 'smooth and continuous' taper, the following significant differences were found (greater number of teeth with 'smooth and continuous' taper are in italic): between *mandibular molars* and maxillary anteriors (OR 0.30, 95% CI 0.16, 0.55); *mandibular molars* and maxillary premolars (OR 0.29, 95% CI 0.16, 0.55); *maxillary molars* and maxillary premolars (OR 0.42, 95% CI 0.22, 0.80); maxillary anteriors and *maxillary molars* (OR 2.36, 95% CI 1.25, 4.47).

Extrusion

No sealer extrusion occurred most frequently with mandibular premolars (71.4%), with large amounts of sealer extrusion occurring with maxillary anteriors (6.4%). A statistically significant difference was found amongst the operators ($P = 0.008$). Additionally, with reference to 'no or small' sealer extrusion, the following significant differences were found (greater number of teeth with 'no or small' sealer extrusion are in italic): between mandibular anteriors and *maxillary molar* (OR 0.38, 95% CI 0.14, 1.00); *mandibular molars* and maxillary anteriors (OR 2.07, 95% CI 1.20, 3.56); *mandibular premolars* and maxillary anteriors (OR 2.70, 95% CI 1.06, 6.89); maxillary anteriors and *maxillary molars* (OR 0.47, 95% CI 0.27,0.83).

Greater amount of sealer extrusion was found in teeth that were previously accessed ($P = 0.009$) as well as in teeth that were being re-treated ($P = 0.03$).

Apical enlargement

There was a statistically significant difference amongst operators with regard to apical enlargement ($P < 0.001$). There was also a significant difference between endodontic treatment and re-treatment ($P < 0.001$) with the mean apical enlargement found to be ISO size 38.1 for endodontic treatment and 44.7 for re-treatment.

Outcome assessment–adequate endodontic treatment

Table 5 shows the outcome assessment according to the definition described earlier.

Table 5 Outcome assessment (adequate endodontic treatment) based on Molander *et al.* (2007)

Definition of adequate treatment	Frequency	%
Definition 1[a]	1045	77.4
Definition 2[b]	1229	91.0
Total	1351	

[a]Correct length (within 2 mm of the radiographic apex), adequate lateral seal, smooth and continuous taper, and no transportation.
[b]Correct length (within 2 mm of the radiographic apex), adequate lateral seal, lack of taper and/or no transportation.

Discussion

Epidemiological studies have consistently shown that the high prevalence of disease found in root-filled teeth is related to the poor technical quality of root fillings. These studies have found a very high percentage of inadequate root fillings, in the range of 49–87% (Ödesjö *et al.* 1990, Buckley & Spångberg 1995, Weiger *et al.* 1997, Marques *et al.* 1998, Sidaravicius *et al.* 1999, Tronstad *et al.* 2000, Dugas *et al.* 2003, Er *et al.* 2006). However, many of these epidemiological studies were undertaken in general practice or hospital settings. Conversely, outcome studies (Strindberg 1956, Engström *et al.* 1964, Sjögren *et al.* 1990) conducted in controlled environments have shown that when root fillings are of a high technical standard, the presence of disease (preoperative periapical radiolucency) appears to have a minimal influence on the outcome of root canal treatment. Additionally, the survival rate of teeth treated by endodontists was shown to be significantly better than those treated by general practitioners (Alley *et al.* 2004). It has been demonstrated that highly skilled operators are less likely to perform procedural errors that may ultimately compromise the prognosis (Ingle *et al.* 1994).

The current study analysed the technical standard of root fillings achieved by endodontists using clinical and radiographic records. To minimize the effect of variation between individual observers, the opinion of many observers has been proposed (Goldman *et al.* 1972). Therefore, it was decided in consultation with a statistician that three examiners would be used and a consensus on each variable would be reached. The ability to reach a consensus also appeared to be a more appropriate form of assessment because of the qualitative nature of many of the variables. The authors attempted to minimize interobserver variability as well as the issue of nonstandardized radiographs, by evaluating all radiographs available for each case, as has been previously proposed (Brynolf 1967, Lambrianidis 1985) for this purpose.

Alley *et al.* (2004) reported that endodontists predominantly treat posterior teeth. This was consistent with the findings of this study where 61.8% of treated teeth were molars. The majority of treatment performed was initial treatment (81.1%) with approximately half of the cases (49.7%) being accessed by the referring dentist.

The introduction of rotary NiTi instruments has allowed the clinician to minimize procedural errors such as canal transportation, zipping and ledging (Pettiete *et al.* 1999, Schäfer *et al.* 2004). The minimal number of straightened canals and minimal procedural errors noted in this study confirm earlier findings that the use of rotary NiTi minimizes iatrogenic errors (Esposito & Cunningham 1995, Glossen *et al.* 1995, Schäfer & Schlingemann 2003), as well as the skill of experienced endodontists. NiTi instruments also allow the safer instrumentation of canals to a larger apical size with a consistent taper. Instrumentation to larger apical sizes may be required to more effectively remove culturable micro-organisms from within the canal (Dalton *et al.* 1998, Shuping *et al.* 2000, Card *et al.* 2002). The six endodontists in this current study all used rotary NiTi instruments as part of their instrumentation technique. Interestingly, variability in apical enlargement size was noted amongst the operators ($P < 0.001$). This may relate to the different biological principles of the operators, with some relying predominantly on intracanal irrigants and/or medicaments in order to minimize the presence of micro-organisms within the root canal. Others appeared to rely on the mechanical instrumentation of the canal. It is possible that past experience may dictate the decision-making process of the clinician. The clinician may not want to greatly alter a technique that has proved effective for them in the past (Parashos & Messer 2006). There was also a statistically significant difference between initial treatment and re-treatment with regard to apical enlargement ($P < 0.001$). This finding would most likely be because of the need to first remove the existing root filling followed by re-cleaning and shaping of the root canal system.

Proximity of the root canal filling to the radiographic apex has consistently been shown to significantly affect the outcome of conventional root canal treatment. The highly controlled long-term outcome study by Sjögren *et al.* (1990) found that in the presence of apical periodontitis, roots filled close (0–2 mm) to the apex were associated with healing in 94% of cases, but those

that were filled short (> 2 mm) and those that were overfilled had healing rates of 68% and 76%, respectively. Most studies have considered apical termination within 2 mm of the radiographic apex to be the gold standard, whereas others have adopted a standard of 3 mm (Marques *et al.* 1998, Sidaravicius *et al.* 1999, Kirkevang *et al.* 2000, Segura-Egea *et al.* 2004). The use of the measuring tool on Adobe Photoshop CS2 9.0.2 allowed an accurate measurement of the proximity of the root canal filling relative to the radiographic apex and therefore enabled a stricter definition of what constituted an acceptable length of root filling. The accuracy of the measurement is limited by the use of nonstandardized radiographs, which may lead to a small inaccuracy because of distortion/angulation. Further, the apical foramen may not be at the radiographic apex. These limitations apply to all similar studies where standardization is impractical. The analysis of all relevant radiographs allowed the examiners to score the radiograph that they deemed to be most accurate with minimal parallax error. The stricter criteria still found 72.7% of roots to be filled within 1 mm of the radiographic apex. A more traditional criterion found 91.8% of roots to be filled 2 mm from the radiographic apex. It is reasonable to assume that the previously treated teeth had a greater likelihood of a ledged or straightened canal, hampering the ability of the endodontist to fully negotiate the canal. Nevertheless, no statistically significant difference was found between initial endodontic treatment and re-treatment ($P = 0.9$).

There is conflicting evidence regarding the impact of root filling density on prognosis. Studies have shown that teeth with homogenous root fillings will result in more consistent healing (Kerekes & Tronstad 1979) and survival (Stoll *et al.* 2005). Some authors revealed no difference in the prognosis of root canal treatment (Sjögren *et al.* 1990), whereas others found nonhomogenous and inadequately compacted root fillings to have a significantly increased prevalence of apical periodontitis (Kirkevang *et al.* 2000, Dugas *et al.* 2003, Segura-Egea *et al.* 2004). Studies that have investigated density have also analysed the lateral adaptation of the root canal filling, with void detection in the lateral aspect of the root filling considered to be inadequate (Kirkevang & Hörsted-Bindslev 2002). However, Eckerbom & Magnusson (1997) found that the reliability of assessing density and lateral seal with one orthoradial intraoral radiograph was poor. Hence, all relevant radiographs were assessed by the examiners in this study to increase the reliability of the ratings. Although there would have been differences in the filling technique of each operator, they all used a combination of cold lateral and warm vertical compaction. Despite the variation of filling techniques amongst operators, this study found a high percentage of adequately sealed root canals with homogenous (86.1%) and dense (88.6%) root fillings.

The European Society of Endodontology (2006) has suggested that the root canal be tapered from crown to apex. This criterion has not been widely analysed in the literature (Barrieshi-Nusair *et al.* 2004, Er *et al.* 2006), which may be because of the subjectivity of assessing this variable radiographically. This study found that the majority of canals had a 'smooth and continuous' taper (83.8%), which indicates the benefits of rotary NiTi instrumentation.

Assessment of the overall technical standard found that 64.5% of cases were deemed to be adequate when the root filling terminated within 2.0 mm from the radiographic apex, and a homogenous and dense filling was noted within the entire canal together with an adequate lateral adaptation. This finding was higher than that of the only other study that investigated the technical standard of endodontic treatment performed by endodontists. In the study by Dugas *et al.* (2003), 51.3% of cases were found to be adequate. However, rotary NiTi has changed both instrumentation and filling philosophies. Canals are now instrumented to a consistent taper and with minimal transportation (Pettiette *et al.* 1999, Schäfer *et al.* 2004). This allows for filling with gutta-percha cones that are matched in both apical size and taper. It therefore seems appropriate that other factors be analysed with regard to the technical standard of root fillings that relate to the use of rotary NiTi instruments. In the recent study by Molander *et al.* (2007), assessment of the quality of root filling included the parameters of taper and canal transportation, together with the quality of seal and length. The assessment in the current study was based on the work by Molander *et al.* (2007). However, a stricter criterion was utilized, whereby the root filling was required to terminate within 2 mm of the radiographic apex. Using this criterion, adequate root fillings in the present study ranged from 77.4 to 91.0%.

The endodontists who participated in this study varied in their instrumentation and filling philosophies. Additionally, the techniques and rotary NiTi systems differed amongst operators. Despite this, analysis of the individual variables together with the overall outcome assessments suggested all operators placed root fillings

that complied with current guidelines in a high proportion of roots.

Conclusion

The technical quality of root fillings performed by endodontists in Melbourne, Australia complied with current guidelines in 77.4–91.0% of roots. All variables examined confirmed high levels of technical proficiency. There were very few instances of canal transportation and/or procedural errors.

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