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A prospective study on the effect of coronal tooth structure loss on the 4-year clinical survival of root canal retreated teeth and retrospective validation of the Dental Practicality Index

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Abstract

Al-Nuaimi N, Ciapryna S, Chia M, Patel S, Mannocci F. A prospective study on the effect of coronal tooth structure loss on the 4-year clinical survival of root canal retreated teeth and retrospective validation of the Dental Practicality Index. *International Endodontic Journal.*

Aim First, to examine the impact of the residual volume of coronal tooth structure in posterior teeth measured with an intra-oral scanner on the 4-year clinical survival of root canal retreated teeth. Secondly, to assess retrospectively the effectiveness of the Dental Practicality Index (DPI) in predicting the survival of root canal retreated teeth.

Methodology A total of 156 posterior root canal treated teeth (140 patients) had baseline periapical radiographs (PA) and cone-beam computed tomography (CBCT) scans taken prior to root canal retreatment. These teeth were followed up with a clinical examination at 1, 2, 3 and 4 years (T12, T24, T36 and T48) with periapical radiographs and CBCT images taken at T12, and PA taken at T24, T36 and T48 where appropriate. Root canal retreated teeth were dichotomized into 'survived' versus 'extracted'. Fisher's exact test was used to determine the association between the volume of remaining coronal tooth structure and the 4-year tooth survival. The Dental Practicality Index for each tooth was established using the preoperative clinical and radiographical data. Fisher's exact test was used to establish a relationship between categorical variables, the total score of DPI vs tooth outcome.

Results The percentage of extractions associated with teeth with <29.5% remaining coronal tooth structure was 3 times higher (12.5%) compared to that of teeth with a residual tooth structure > 29.5% (3.5%), but with no significant difference ($P = 0.073$). There was a significant correlation between the outcome of root canal retreatments at 1 year, assessed by both PA and CBCT, and the 4-year survival (Fisher's exact test, $P = 0.007$ and $P = 0.001$, respectively). Teeth with DPI scores ≥ 6 were more likely to be extracted than teeth with DPI score < 6 (18.8% vs. 3.9%) (Fisher's exact test, $P = 0.045$).

Conclusion Teeth with <30% of remaining tooth structure were associated with a survival rate above 80% and teeth with more than 30% of residual tooth structure survived in more than 94% of the cases. The radiographic outcome of root canal treatment can also help to predict tooth survival with teeth having an unfavourable outcome at 1 year more likely to be extracted within 4 years of completion of treatment. The DPI score can potentially be used to identify teeth with failed root canal treatment, which are likely to be extracted following retreatment and cuspal coverage.

Keywords: coronal tooth structure, Dental Practicality Index, root canal retreatment, tooth survival, treatment outcome.

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Introduction

The preservation of coronal tooth structure without compromising root canal access has been shown to be desirable when planning root canal treatment (Mannocci & Cowie 2014). Various studies have looked at the amount of coronal dentinal walls present and assessed how this could affect the fracture resistance (Nam *et al.* 2010) or survival of a particular tooth (Creugers *et al.* 2005, Nagasiri & Chitmongkolsuk 2005, Naumann *et al.* 2005). The design of studies that aim to assess fracture resistance or survival shows considerable variation.

Nagasiri & Chitmongkolsuk (2005) reviewed retrospectively 220 root canal treated molar teeth in 203 patients to assess how the remaining tooth structure and the type of restorative material used to restore noncrowned teeth affected survival. They found that the overall survival estimates of molar teeth with maximum and minimum tooth structure after 5 years were 78% and 18%, respectively. The authors developed a classification for the amount of coronal tooth structure remaining. However, they did not outline how they measured the thickness of the walls in assessed teeth, nor did they advise how this classification could apply to the measurements of teeth with differing thicknesses and heights of remaining walls.

The influence of the number of remaining coronal walls and placement of a pre-fabricated or customized fibre post on the 3-year survival of root canal treated premolars was examined by Cagidiaco *et al.* (2008). The follow-up period was extended by Ferrari *et al.* (2012) to assess the 6-year clinical survival. The overall results revealed that the number of coronal walls and the presence of a post significantly affected the 3- to 6-year failure risk of root canal treated premolars.

Other studies have investigated how the height of retained coronal tooth structure may impact on fracture resistance, especially with cast posts and cores. Creugers *et al.* (2005) found that the type of post-core or direct bonded composite dowel type core restoration did not affect survival; the amount of dentine height after preparation was, however, crucial in influencing the longevity of a post-core restoration (Creugers *et al.* 2005). The volume of remaining coronal tooth structure is likely to be a crucial factor in the survival of a root canal treated teeth.

In a recent root canal treatment outcome cone-beam computed tomography (CBCT) study (Al-Nuaimi *et al.* 2017a), it was found that teeth with <30% of coronal tooth structure remaining post root canal retreatment were more likely to fail 1-year post-treatment. In this study, the volume of residual coronal tooth structure was assessed, rather than measuring thickness and/or height of residual tooth structures.

The 'Dental Practicality Index' (DPI) (Dawood & Patel 2017) considers the practicality of restorative treatment. Each of the restorative categories: endodontic status, periodontal status, structural integrity and the context (i.e. local and general factors), is assessed and scored (0, 1, 2 or 6). After scoring each category, the sum of scores is used to determine the DPI score. A DPI score ≥ 6 indicates that attempting to restore the tooth may not be advisable and other treatment options should be considered and discussed with the patient (Table 1).

A recent retrospective study (Tifooni *et al.* 2019) demonstrated that the DPI could be used to effectively predict the outcome of root canal treatments.

A clinician must always verify if a proposed treatment is in the patients' best interest and if the selected treatment plan is likely to have a good long-term prognosis. Being able to provide clinicians with an accurate estimate of the probability of survival and success following root canal treatment and retreatment will help the patient in making an informed decision. If a clinician can confidently estimate the survival of a root canal retreated tooth when a particular volume of coronal tooth structure remains, they can discuss with the patient a plan to preserve the tooth or alternately agree to extract the tooth and provide a suitable prosthodontic alternative.

The literature is sparse on the survival of root canal treated teeth based upon the true volume of the coronal tooth structure remaining post root canal treatment. This present study continues from the study conducted by Al-Nuaimi *et al.* (2017a), which concluded that root canal retreated teeth, which had less than 30% of their original tooth volume, had a 2.58-fold greater chance of an unfavourable root canal treatment outcome.

Table 1 Dental Practicality Index (DPI) (Dawood & Patel 2017)

Weighting	Structure integrity	Periodontal treatment need	Endodontic treatment need	Context
0 No treatment required	Unrestored or existing well-adapted restoration	Probing < 3.5 mm (BPE 0-2) Previously successfully treated periodontal disease	Vital pulp Previously successfully treated endodontic disease	Local: Isolated dental problems where adjacent teeth are healthy General: Replacing of a strategic tooth may be excessively complex History of IV bisphosphonates, head and neck radiotherapy
1 Simple treatment required	Simple (in)direct restoration	Probing 3.5–5.5 mm (BPE 3) root surface debridement indicated	Simple root canal system with endodontic disease (e.g. radiographically easily identifiable root canal[s], easily retrievable root canal filling material)	Local: Prosthodontic treatment planned of neighbouring teeth that may influence treatment plan for tooth being assessed Tooth to be used as a bridge abutment General: Radiotherapy of head and neck region planned Immunocompromised patient
2 Complex treatment required	Minimal residual sound tooth structure (e.g. subgingival margins, post-core restoration required)	Probing> 5.5 mm (BPE 4) compromised support (e.g. short root, crown lengthening required, grade 2 mobility) Grade 2–3 furcation involvement	Complex root canal system with endodontic disease (e.g. sclerosed root canal, acute curvatures). Complex re-root canal treatment (e.g. fracture instrument removal, perforations) Difficulty in obtaining anaesthesia	Local: Prosthodontic treatment planned of multiple, including adjacent teeth General: High caries rate Poor oral hygiene Parafunctional habits, extensive tooth surface loss Active periodontal disease
6 Impractical to treat	Inadequate structure for ferrule	Untreatable periodontal disease	Untreatable root canal system	Local: Retention of the tooth being assessed would constrain and/or compromise an otherwise simple and predicable treatment plan (e.g. extensive bridgework) General: Potentially life-threatening medical conditions that should be managed in tertiary care

The primary aim of the present study was to establish whether the volume of remaining coronal tooth structure, measured with an intra-oral scanner post root canal retreatment in posterior teeth, had an effect on the 4-year survival of root canal retreated teeth. The second aim was to assess retrospectively the effectiveness of the DPI in predicting the survival of the root canal retreated teeth included in the present study.

The first null hypothesis tested was that the residual volume of the coronal tooth structure does not affect the survival of root canal retreated teeth. The

second null hypothesis was that there was no difference in the percentage of 4-year survival of teeth with different DPI scores.

Materials and methods

Patients (>18 years old) with posterior root canal treated teeth diagnosed with post-treatment endodontic disease were included in the trial. The details of the inclusion and exclusion criteria, study design, follow-up examination and outcome assessments have been reported previously (Al-Nuaimi *et al.* 2017a).

Ethical approval for the clinical study was granted by the Guy's and St Thomas' Hospital National Health Service Trust and R&D office (reference: RJ113/N237) and the NRES West-London Research and Ethics Committee (reference: 13/LO/1171). Informed verbal and written consent was obtained from all patients before enrolment.

Overall, a total of 204 posterior teeth (182 patients) were initially included within the original study. Forty-eight teeth were further excluded for reasons such as withdrawal of consent, lack of restorability of the tooth in question, no possible further contact with the patient or patients' passing away. PA and CBCT scans were undertaken preoperatively (T0) and 1 year (T12) after root canal retreatment completion (Al-Nuaimi *et al.* 2017a).

Root canal retreatments and all restorative work including cuspal coverage restorations were completed by 20 endodontic post-graduate students under the direct supervision of endodontic specialists. All operators were appropriately trained and pre-calibrated to follow a protocol consistent with ESE guidelines (European Society of Endodontology 2006). After the T12 clinical and radiographic evaluation, patients were invited back for further yearly clinical assessment, for a period of three further years (at years 2 (T24), 3 (T36) and 4 (T48)) and periapical radiographic evaluation if the outcome was deemed unfavourable at the 1-year review (Fig. 1).

Of the patients that attended reassessment, a full dental examination was once more carried out. A detailed patient history was taken, clinical examination including all dental soft and hard tissues recorded, with a close evaluation of the tooth treated.

The teeth were judged to have 'survived' if they were functioning in the oral cavity at their follow-up review regardless of the presence or absence of radiographic apical radiolucencies.

To identify whether the root canal retreated tooth had survived, patients were asked to attend a clinical review appointment. For those who did not attend and were contacted by phone, a pre-set of questions was prepared beforehand to standardize the patient responses and rule out patient-related error (Table 2).

Over the T24, T36 and T48 recall periods, patients were either 'clinically' assessed (attended a clinical review appointment) or 'not clinically' assessed (patients were contacted by telephone only).

Each of the DPI categories (structural integrity, periodontal status, endodontic status, context) was assessed by two experienced calibrated endodontists as described previously (Tifooni *et al.* 2019).

Data analysis

Statistical analysis was carried out using IBM SPSS software (version 24; IBM, New York, NY, USA). Root canal retreated teeth were dichotomized into 'survived' versus 'extracted'. In order to determine the association between the volume of remaining coronal tooth structure and the survival of root canal retreated teeth, the raw volume was analysed using receiver operating characteristic (ROC) curve and Youden's index (sensitivity + specificity-1) to identify the optimal cut-off point for volume dichotomization. A Chi-square/Fisher's exact test was used to determine any possible association between the volume of remaining coronal tooth structure and the 4-year outcome.

A Chi-square/Fisher's exact test was applied to investigate whether the failure of the root canal retreatment, determined by PA and CBCT, at 1 year had an effect on the 4-year survival of root canal retreated teeth.

Similarly, a Chi-square/Fisher's exact test was used to establish a relationship between categorical variables, the total score of DPI vs tooth outcome. The significance level was set at $\alpha = 0.05$.

Results

In total, 156 teeth in 140 patients had root canal retreatment completed. The follow-up time ranged from 12 months to 60 months. The median follow-up time was 36 months, whilst the average follow-up time was 4.3 years.

At T12, 137 teeth (121 patients) out of the original 156 teeth (140 patients) were available for evaluation. The initial recall rate at T12 was 86% for

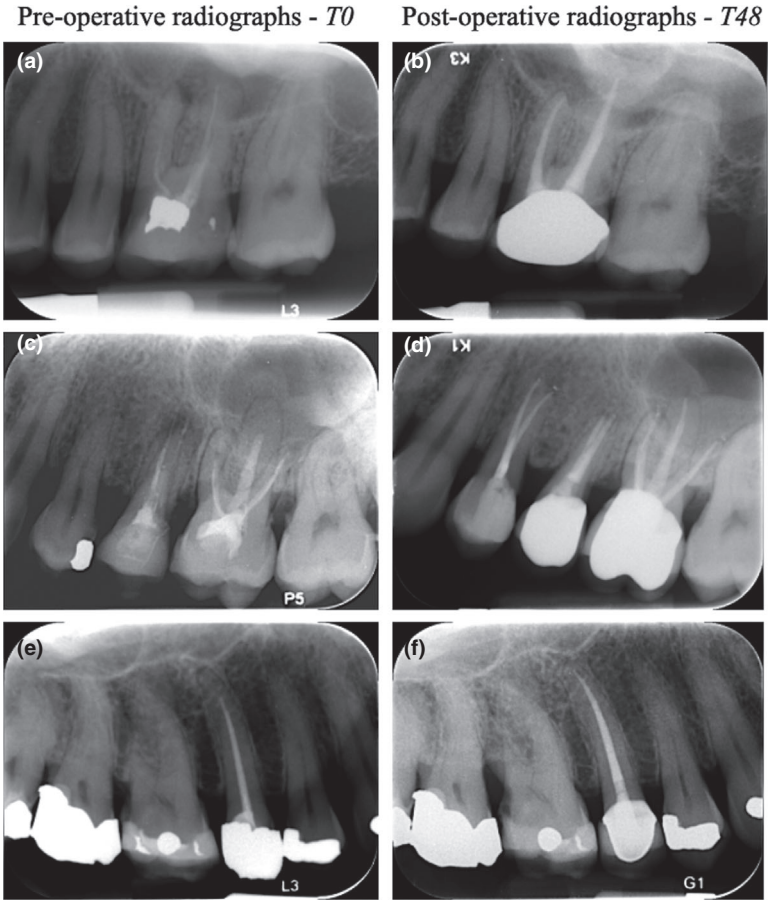

Figure 1 Selected periapical radiographs taken at T0 and T48. (a) preoperative radiograph (T0) of 26 showing periapical radiolucencies on mesiobuccal and palatal roots, (b) 4-year (T48) postoperative radiograph showing complete resolution of the periapical radiolucencies on the mesiobuccal and palatal roots, (c) preoperative radiograph of 25 showing periapical radiolucencies on buccal and palatal roots, (d) 4-year postoperative radiograph showing complete resolution of the periapical radiolucencies on the buccal and palatal roots, (e) preoperative radiograph of 15 showing periapical radiolucency on buccal root, (f) 4-year postoperative radiograph showing complete resolution of the periapical radiolucency on the buccal root.

patients and 88% for teeth. Three teeth were extracted in the first year. These had unfavourable outcomes (Table 3).

At the T24 recall, the total number of patients who could be contacted was 116. The 'clinically assessed' recall rate was 62%. A further 5 teeth were extracted. Of these extracted teeth, 3 had unfavourable outcomes at T12 and 2 did not. Eight teeth were extracted in total.

The T36 clinical recall rate dropped further to 51%. The number of patients contacted by telephone only, however, increased to 122 patients. No new extractions were recorded.

At the T48 recall, the pooled (clinically and non-clinically assessed) recalls included 127 patients (144 teeth): 45 patients (61 teeth) were clinically examined and 82 patients (83 teeth) were contacted by telephone. The clinical recall rate for patients was 32% and for teeth was 39%. Therefore, the difference in clinical recall rate between T12 and T48 for patients and teeth was 54% and 49%, respectively. No new extractions were recorded (Table 3).

Of the 8 teeth that were extracted, 6 had unfavourable root canal treatment outcome, and of these teeth, 4 had less than 29.5% coronal tooth structure present. All extracted teeth were molars. The tooth types

Table 2 Questionnaire asked to patients when contacted by telephone

	Questions	Answers
1	Is the root canal retreated tooth still present in the mouth (survived)?	Yes/ No
2	If the tooth was extracted, why was it extracted?	Reason known to patient
3	Can you identify which tooth this was?	Tooth Number/ Type
4	On which side of the mouth was the root canal treatment carried out?	Left/ Right
5	Was the root canal treatment carried out on the upper or lower (jaws)?	Maxilla/ Mandible
6	Does the tooth with the root canal treatment cause any pain?	Type of pain/ Duration/ Frequency

and their corresponding volumes are shown in Table 4.

At T48, 6 patients (7 teeth) who had not responded to communication when trying to arrange the T12, T24 or T36 recall appointments were contacted by telephone and the status of their teeth was noted.

Eight of the patients who were contactable at T48 did not attend the T12 clinical and radiographic review appointment; therefore, no PA or CBCT data were available. These patients continued to be followed for survival but were excluded from the analysis of the association between PA and CBCT outcome at 1 year against the survival of teeth at 4 years (Fig. 2).

Based on Youden's index associated with ROC curve, the optimal cut-off point of remaining tooth volume was 29.5% for both the 'clinical' and 'non-clinical' recall data. As the optimal cut-off point for remaining tooth volume was ascertained to be

Table 4 The extracted teeth and percentages (%) of coronal tooth structure remaining after root canal retreatment

Tooth	% Residual tooth structure
UL6	17.44
LR6	17.67
LR7	29.49
UR6	29.59
LL6	34.52
UR6	40.12
LR7	45.25
LR6	52.37

29.5%, the remaining coronal volume of teeth in pooled recall data was dichotomized into less than 29.5% ($n = 32$) and more than 29.5% ($n = 112$). Sixty-one teeth were clinically reviewed at 4 years. Fourteen teeth had a volume below 29.5% (10 survived vs 4 extracted), and 47 teeth had a volume above 29.5% (43 survived vs 4 extracted). Fisher's exact test gave a *P*-value of 0.073 and, therefore, did not reach statistical significance (Table 5).

The percentage of extractions associated with teeth with less than 29.5% remaining coronal tooth structure was 3 times higher (13%) compared with teeth with a residual tooth structure> 29.5% (4%). The correlation between the percentage of remaining coronal tooth structure (<29.5%, >29.5%) and tooth survival did not reach statistical significance (Fisher's exact test, $P = 0.073$, odds ratio [OR], 0.259; 95% CI: 0.061–1.102) (Table 5).

Overall survival at 4 years was 94%. There was a significant correlation between tooth outcome at T12 assessed by CBCT and the 4-year survival (Fisher's exact test, $P = 0.001$). Teeth with an unfavourable outcome with CBCT at 1 year are more likely to be

Table 3 Breakdown of clinical and phone recalls of patients throughout the 4-year period

	T12	T24	T36	T48
Clinical + phone recalls	137 teeth (121 patients)	131 teeth (116 patients)	138 teeth (122 patients)	144 teeth (127 patients)
Teeth survived	134	123	129	136
Teeth extracted	3	8	8	8
Recall rate				
Teeth	87.8%	84.0%	88.5%	92.3%
Patients	86.4%	82.9%	87.1%	90.7%
Clinical recalls only	137 teeth (121 patients)	103 teeth (87 patients)	76 teeth (72 patients)	61 teeth (45 patients)
Recall rate				
Teeth	87.8%	66.0%	48.7%	39.1%
Patients	86.4%	62.1%	51.4%	32.1%

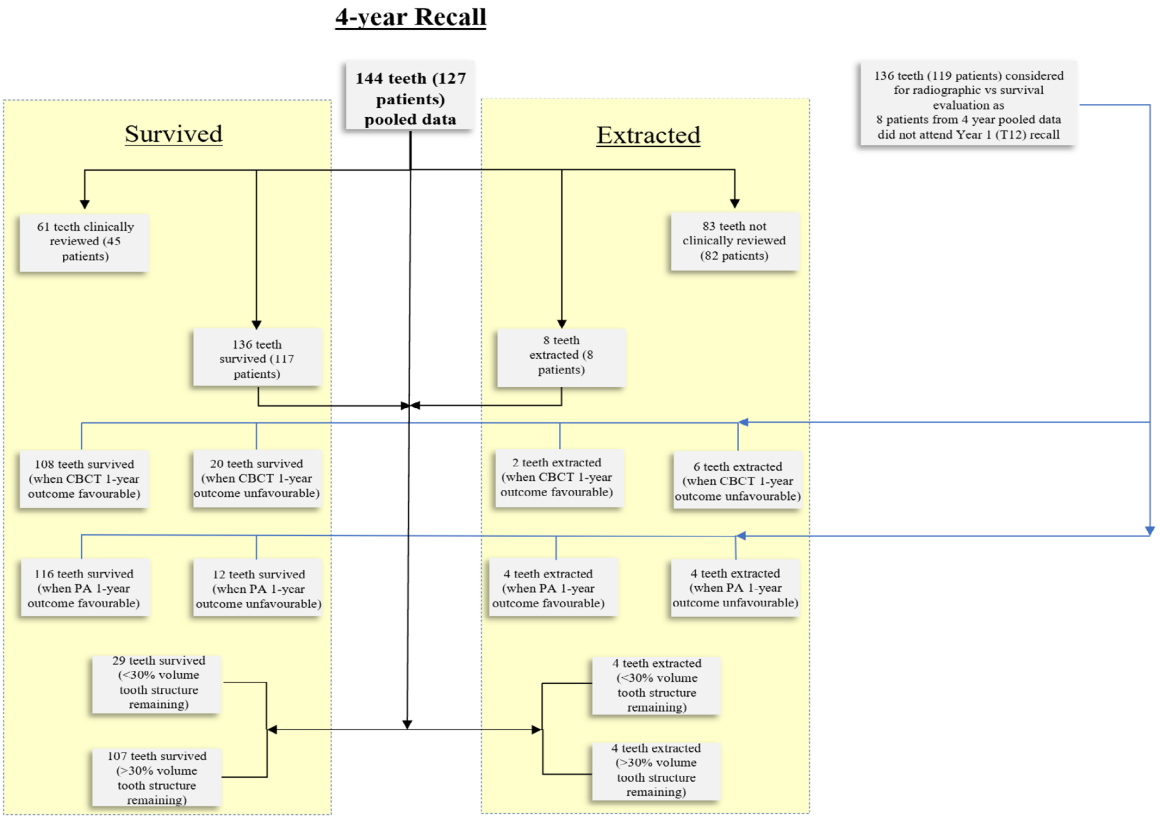

Figure 2 Flowchart of the trial showing extracted and nonextracted teeth based upon radiographic outcome and volume of coronal tooth structure remaining.

Table 5 Evaluation of volume of tooth structure remaining and numbers of extracted teeth

Volume of remaining tooth structure	No. of survived teeth	No. of extracted teeth	Total	% of extraction
Clinically reviewed teeth				
<29.5%	10	4	14	28.6
>29.5%	43	4	47	8.5
Total	53	8	61	13.1
Pooled data (clinical and phone recalls)				
<29.5%	28	4	32	12.5
>29.5%	108	4	112	3.6
Total	136	8	144	5.6

Table 6 Correlation between CBCT/PA outcome at 1 year and tooth survival at 4 years

CBCT outcome	No. of survived teeth	No. of extracted teeth	Total	% of extraction
CBCT				
Favourable	108	2	110	1.8
Unfavourable	20	6	26	23.1
Total	128	8	136	
PA				
Favourable	116	4	120	3.3
Unfavourable	12	4	16	25
Total	128	8	136	

extracted after 4 years than those with favourable outcomes (23% to 2%) (Table 6).

There was also a significant correlation between tooth outcome at 1 year assessed by PA and the 4-year survival (Fisher's exact test, $P = 0.007$). Teeth with an unfavourable outcome with PA at T12 were more likely to be extracted after 4 years than teeth with favourable outcomes (25% to 3%) (Table 6).

One hundred and forty-four teeth were available at T48 for the assessment of tooth survival according to the DPI scores (Table 7).

The intra-examiner agreement for the DPI score using Cohen kappa statistic was 0.59.

Teeth with DPI score ≥ 6 were more likely to get extracted after 4 years than were teeth with DPI score < 6 (19% vs. 4%) (Fisher's exact test, $P = 0.045$) (Table 7).

Table 7 Overall survival of teeth according to the DPI scores

DPI score	Tooth outcome			Extraction (%)	*P*-value
	Survived	Extracted	Total		
<3	33	1	34	2.9	0.681
≥3	103	7	110	6.4	
<4	77	4	81	4.9	0.730
≥4	59	4	63	6.3	
<5	101	4	105	3.8	0.212
≥5	35	4	39	10.3	
<6	123	5	128	3.9	0.045
≥6	13	3	16	18.8	

Discussion

The most significant finding from this study was that the outcome of root canal retreatment at 1 year was predictive of tooth survival at 4 years. Failure of the root canal retreatment, assessed with PA and CBCT, at T12 was associated with a higher proportion of extractions at T48. There was a 0.4% disparity between the percentage of tooth extractions when comparing the data for CBCT and PA (23.1–1.8% = 21.3% and 25–3.3% = 21.7%, respectively). Both CBCT and PA (23.1% and 25%) indicated that approximately one-quarter of teeth that had an unfavourable outcome at T12 went on to be extracted at the T48 recall. This was in stark contrast to the teeth, which had a favourable outcome (1.8% extracted with favourable CBCT outcome/3.3% extracted with favourable PA outcome).

The results show that although the residual volume of coronal tooth structure affecting tooth survival was not statistically significant, there was a distinct trend towards significance ($P = 0.073$, [OR], 0.259; 95% CI: 0.061–1.102). This indicates that clinicians can, with a certain amount of predictability, plan root canal retreatment on teeth that are volumetrically compromised (low volume), if a strict protocol is followed and an adequate cuspal coverage restoration is provided immediately after the completion of the root canal treatment. The first null hypothesis is, therefore, upheld.

The first part of this study (Al-Nuaimi *et al.* 2017a) was the first of its kind to accurately investigate the significance of the volume of coronal tooth structure remaining on the radiographic outcome of root canal retreated teeth. That study concluded that teeth, which had less than 30% of their original tooth volume, had a 2.58-fold greater chance of an unfavourable outcome (95% CI: 1.026, 6.487) at T12. As such, it was postulated that the lack of coronal tooth structure may have complicated the root canal treatment. Factors such as difficulty in isolation, inability to form an adequate coronal seal and increased risks of fractures or cracks will have hindered treatment and outcome/survival.

Only premolar and molar teeth undergoing root canal retreatment in occlusal function with natural opposing teeth and without periodontal probing > 3mm were included in this study (Al Nuaimi *et al.* 2017a). Parafunction habits and/or the presence of (non)working side contacts might have affected tooth survival; however, they could not be taken into consideration in the original outcome study (Al Nuaimi *et al.* 2017a) as they would have limited the recruitment capability. Six of the 8 extracted teeth had an unfavourable root canal treatment outcome (CBCT), indicating that root canal retreatment failure must have been the main reason for the extractions; similarly, this clinical trial was powered for the assessment of the effect of the residual coronal tooth structure on the root canal retreatment outcome and, not for its effect on survival, this may partially explain the narrowly missed survival end-point in relation to the residual coronal tooth structure.

As expected in long-term follow-up trials, the difference in clinical recall rate for patients and teeth between T12 and T48 was 54% and 49%, respectively.

In total, 127 out of the original 140 patients who had root canal retreatment were contacted (91%). This equates to 144 out of 156 teeth (92%). Though it can be argued that unless a tooth was visualized by a suitably trained and calibrated clinician, it cannot be considered to have survived, and the benefit that the authors of this paper have is the fact that the T48 review was preceded by a T12, T24 and T36 clinical and patient contact review. This gives the study increased reliability as the findings at T48 could be corroborated by previous clinical reviews and annual patient contact over the 48 months this trial lasted.

The total survival rate for the pooled data was 94%. This is similar to the 86%-93% survival rate after root canal treatment quoted by the systematic review of Ng *et al.* (2010). In a well-controlled prospective clinical trial conducted in the same geographic area, Ng *et al.* (2011) reported a 4-year tooth survival following secondary root canal treatment of 95%.

Research has been undertaken that correlates the survival of root canal treated teeth restored with posts (Ferrari *et al.* 2007, 2012, Sterzenbach *et al.* 2012, Skupien *et al.* 2013) and different types of coronal

restorations (Nagasiri & Chitmongkolsuk 2005, Bitter *et al.* 2009). Such studies have relied on qualitative means as opposed to accurate quantitative methods to measure the volume of tooth structure remaining.

This study, using an accurate digital scanner, allowed for detailed quantitative figures to be analysed, thereby improving the reliability of results (Al-Nuaimi *et al.* 2017b). What is important to note is that the survival rate in this study related to root canal retreatments of posterior teeth. Secondary root canal treatments are complicated by various factors, such as iatrogenic perforation, patency at the terminus, extrusion of root fillings and proximal contacts (Ng *et al.* 2010).

In this study, root canal retreatment was carried out by pre-calibrated postgraduate endodontic students who worked under specialist supervision in a dental teaching hospital. Although there may have been limited differences in the experience level of these postgraduate students, whether that be the endodontic or restorative component of the treatment, a standardized protocol was followed for both the root canal retreatment and crown preparation of teeth. All cores were placed in the same fashion with the same materials, and metal ceramic crowns were provided to definitively restore all teeth. Other studies have a high level of variability such as a clinician's experience (undergraduate, general dentist, postgraduate, specialist) and also differ in the location of teeth to have root canal treatment (whether these be anterior or posterior teeth).

In the pooled recall data, the optimal cut-off point of remaining tooth structure was 29.5%. At T48, the percentage of extracted teeth with less than 29.5% volume remaining was 3 times higher (13%) compared with teeth with a residual volume tooth structure less than 29.5% (4%). This information can give clinicians an indication to the long-term prognosis of root canal retreated posterior teeth. All tooth extractions occurred during the first 2 years after treatment, this is similar to the findings of Ng *et al.* (2011). The number of extracted teeth over this 4-year period was 6% (8 teeth out of 144); posterior root canal retreatments can, therefore, be confidently planned as a first-line treatment option, and even in cases of extreme loss of coronal tooth structure with <30% of coronal tooth structure remaining, an 82% survival at 4 years is expected.

The 5-year survival rate for a dental implant to replace a failing/failed tooth is 96.2% as described in a systematic review (Jung *et al.* 2012). Therefore, it could be concluded that with such a high survival rate of root canal retreatments, which is comparable to the survival of a dental implant, patients would be best advised to undergo retreatment of a posterior tooth with post-treatment disease, especially if the volume of remaining tooth structure is over 29.5%. This nowadays can be easily predicted with intra-oral scanners and specialized software that can correlate different volume data sets to give a percentage difference in volume. Importantly, digital dentistry, including software and hardware, is improving year on year; therefore, it may be feasible in the near future to have intra-oral cameras and software that can give a real-time volumetric analysis whilst taking a photograph to present to a patient.

The DPI can also be useful in predicting the survival of root canal retreated teeth as teeth with a DPI score above 6 had a significantly lower survival than teeth with lower DPI scores. This can help both patient and clinician to make an informed decision as which type of treatment modality to choose and give both parties a degree of confidence in choosing, for example, root canal retreatment, taking into account, in a reproducible manner, structural integrity, periodontal state, endodontic state and general factors, which influence tooth restorability.

Conclusion

In this cohort of root canal retreated teeth, a high proportion of tooth survival was achieved at 4 years. Teeth with less than 30% of tooth structure remaining had a survival rate above 80%, and teeth with more than 30% of residual tooth structure survived in more than 94% of the cases. Most of the teeth that went on to be extracted in year 2 were associated with an unfavourable treatment outcome at the 1-year recall. The DPI score can potentially be used to identify teeth with failed root canal treatment, which are likely to be extracted following retreatment and cuspal coverage.

Conflict of interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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