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ORIGINAL SCIENTIFIC ARTICLE

Technical outcome of root canal treatment on permanent teeth in children: a retrospective study

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Abstract
Aim The aim was to assess the technical quality of root canal treatment conducted in paediatric patients. No specific data is available assessing endodontic treatment quality in children. General adult populations report satisfactory technical quality between 12.8 and 55.7 %, with higher rates by endodontists (77.4–91.0 %).
Methods Radiographs of 100 chronological cases, conducted by staff (categorised as; junior staff, middle grades or consultants) in a UK teaching hospital, were evaluated retrospectively. Technical outcomes were compared to the European Society of Endodontology quality guideline consensus. A satisfactory root filling was defined as having: root filling material <2 mm from the radiographical apex; no canal space seen beyond the end of the obturation and an obturation of homogeneous density with no voids. In addition where MTA was used a plug of ≥3 mm was required. Any variation was considered unsatisfactory treatment.
Results 61 % [95 % CI 51–70 %] of cases were deemed satisfactory. Of the remaining obturations 20.5 % were short of the apex, 28.2 % had extruded material and 56.4 % contained voids. Patients with co-operation issues, particularly anxiety, had lower technical outcomes ($p = 0.001$) and the use of thermoplastic obturation greatly reduced the chance of void inclusion ($p = 0.004$; OR 0.20 [95 % CI 0.06–0.65]). Although 'staff grade' did not show a statistically significant difference, a trend between experience and quality was suspected.
Conclusion Overall technical quality of treatment was comparable to the higher rates found in the general adult population. Additionally thermal obturation may be superior to cold lateral condensation in improving obturation quality, and anxiety negatively impacts on treatment provision.

Keywords Endodontics · Quality · Paediatrics · Permanent dentition · Obturation · Anxiety · Operator experience

Introduction

Root canal treatment is conducted in children for a number of reasons most commonly as a result of trauma or, less commonly, dental caries. The quality of root canal treatment has been linked to the success and periapical health of endodontically treated teeth on several occasions (Sjogren et al. 1990; Ng et al. 2008; Liang et al. 2012; Di Filippo et al. 2014). A recent in-depth review identified four main variables that promoted success of primary root canal treatment, namely: lack of pre-operative periapical radiolucency, root filling with no voids, root filling extending to within 2 mm of the radiographical apex and satisfactory coronal seal (Ng et al. 2008). These findings are reflected in the European society endodontology guidelines (European Society of Endodontology 2006).

One of the main differences between endodontic treatments in children compared to adults, is the prevalence of immature roots. Loss of vitality is a common sequelae of

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dental trauma and can result in arrested root development, if this occurs prior to maturation. The prevalence of traumatic injuries to the permanent dentition in school aged children has been estimated to be around 25 % and is associated with multiple risk factors including: increased overjet/malocclusion, lip coverage, socio-economic factors, age and gender (Zaleckiene et al. 2014). Immature nonvital teeth can be problematic to treat endodontically for a variety of reasons including: difficult debridement due to inverse canal taper, problematic determination of working length, lack of apical stop affecting ability to obturate satisfactorily and increased risk of root fracture due to lack of root dentine (Mohammadi 2011; Kim and Chandler 2013).

Previously, repeated changes of calcium hydroxide dressings were required to produce an apical barrier and allow obturation of the immature tooth. With the introduction of Mineral Trioxide Aggregate (MTA) in the late 90s, an alternative material became available to construct an artificial barrier. Its benefits include improved biocompatibility, promotion and regeneration of apical tissues and reduced treatment time (Torabinejad and Chivian 1999). In recent years the popularity of MTA has increased and it is now a recognised technique for forming an apical barrier in immature teeth.

Previous studies have looked at the quality of root canal treatment (Boltacz-Rzepkowska and Pawlicka 2003; Segura-Egea et al. 2004; Bierenkrant et al. 2008; Moreno et al. 2013; Ertas et al. 2013; Di Filippo et al. 2014). The adequacy of root canal treatment is overall poor, ranging between 12.8 and 55.7 %. One study focused on the quality of specialist endodontists' treatment and demonstrated higher outcomes (77.4–91.0 %) (Bierenkrant et al. 2008). All of these studies focused on adult populations; no reports specifically considered on technical outcomes of endodontics conducted on permanent teeth, in children, were found. The aim of this study was therefore to provide data on the technical quality of root canal treatment performed on permanent teeth in children and identify variables that may affect the outcome of treatment.

Materials and method

Study design

This was a retrospective evaluation of orthograde root treatments completed at the Paediatric dentistry department of Liverpool University Dental Hospital (United Kingdom). Any orthograde root canal treatments started on a permanent tooth in a child under 16 years of age, by staff members of varying grades of experience, were included for analysis. Exclusion criteria included cases where an undergraduate student had conducted any stage of the endodontic treatment. The electronic radiograph system (Carestream PACS; Carestream, New York, USA) was used to identify cases. Searching for 'xr dental periapical' and the names of the paediatric dentistry consultants generated a list of patients. This list was manually searched to identify cases where root treatments had been conducted in the hospital. The first 100 cases identified retrospectively and chronologically, where included. Where a patient had multiple root treatments all teeth were entered as separate subjects. The radiographs were then cross-referenced against the dental records for a case history and clinical information. Endodontic treatment was conducted by staff with differing levels of expertise. These included junior staff (a maximum of 3 years post-graduation; limited experience and training), middle grades (including clinical tutors, academic clinical fellows and specialist trainees) and paediatric dentistry consultants (highest level of experience and training). All staff had previous education in rotary and hand instrumentation techniques; both stainless steel hand files and the NiTi protaper system (Dentsply, California, USA) were available for use. Cold and thermal obturation methods were available to staff, but obturation with MTA was predominantly performed by middle-grade staff and consultants.

Data was collected under the headings in Table 1 and entered into a database as discrete nominal data sets. For each variable the categories were coded to allow for ease of data analysis.

The project complied with ethical principles and was registered with the clinical effectiveness unit of the hospital.

Sample size calculations

As the aim of the study was to assess the proportion of a population demonstrating a characteristic (i.e. satisfactory root canal treatments), therefore, a sample size calculation for a single proportion was calculated. With no previous comparable data found in the literature an estimated proportion for the number of satisfactory root canal treatments was set at 50 %. This provided the most conservative (therefore minimum) sample size required to ensure the required margin of error for the chosen confidence intervals. A ± 10 % margin of error, with 95 % confidence intervals, was chosen and a sample size of 96 was recommended; this was rounded up to 100 for ease of numerical analysis.

Radiographical information/outcome assessment measure

All radiographs assessed were periapical views taken predominantly by the paralleling technique. The assessment

Table 1 Clinical variables measured

Clinical variables	
Tooth	Use of microscope
1° Endodontic or re-treatment case	Hand or rotary instrumentation technique
Age at endodontic treatment	File system
Apex status	Staff grade
Reason for endodontic treatment	Root end closure method (if applicable)
Use of apex locator	Co-operation issues
Type of trauma (if applicable)	Obturation method

was carried out using the baseline post obturation radiographs taken on the day of the treatment. Eight patients did not have radiographs taken on the day. However, they had one taken within 3 months, except one case which was radiographed at 1 year follow-up due to poor patient attendance.

Grades were given as satisfactory or unsatisfactory based on the variables identified by Ng et al. (2008) (found to influence primary orthograde endodontic outcomes) and the standards set in the European Society of Endodontology quality guideline consensus (European Society of Endodontology 2006).

A satisfactory root filling was defined as:

- Root filling <2 mm from the radiographical apex
- No canal space seen beyond the end of the obturation
- Obturation of homogeneous density with no voids

In addition for open apices (Torabinejad and Chivian 1999)

- MTA ≥3 mm (where applicable)

Each radiograph was evaluated on the technical outcome by two examiners, who were independent from treatment planning and provision. If there was disagreement, then a consensus was reached after discussion. In cases where measurements were debatable (e.g. distance from obturation terminus to radiographical apex), then the measurement tool on the radiographical viewing programme was used. Where possible this was calibrated using a previous working length radiograph.

Statistical analysis

The primary outcome measure for the study was the technical quality of endodontic root canal treatment. Secondary outcomes (variables influencing quality) used the Chi squared test to assess for statistical significance; assuming '$p < 0.05$' as significant. Statistical Analysis was performed using SPSS 22.0 statistical software (IBM, Armonk, NY, USA).

Results

A total of 100 root treatments were examined in 78 patients. The average age at time of treatment completion (SD) was 13.4 years (±2.3), ranging between 8 and 18. The most common reason for pulpal necrosis was loss of vitality following dental trauma, accounting for 84 % of cases. Tables 2 and 3 demonstrate the relevant frequencies of the sample.

Primary outcome: technical quality

Of the 100 cases assessed 61 % were classified satisfactory (95 % CI 51–70 %). Of the unsatisfactory cases (total = 39) the majority presented with non-homogenous obturations and voids within the material (56.4 %), followed by extruded material (28.2 %) and obturation material >2 mm short of the radiographical apex (20.5 %). In cases of open apices (total = 49) where MTA had been used to create an apical seal, a small percentage were of inadequate thickness (18.5 %). This occurred in 12.8 % of all the unsatisfactory cases. Age did not influence outcome with a relatively equal distribution between satisfactory and unsatisfactory groups. Experience did not show an effect on treatment quality, with no statistical difference seen between consultants and middle grades ($p = 0.70$, OR 1.26, 95 % CI 0.40–3.93)/junior staff ($p = 0.27$, OR 0.54, 95 % CI 0.18–1.63), or between middle grades and junior staff ($p = 0.07$, OR 0.43, 95 % CI 0.17–1.07) (Fig. 1).

Child cooperation

Children who demonstrated anxiety or hysterical behaviour resulted in a less satisfactory outcome than those who managed well ($p = 0.001$) or those with other co-operation issues (such as movement during treatment) ($p = 0.002$). Sedation was used infrequently when anxiety or co-operation issues were mentioned (37.5 % of cases). Inhalation

Table 2 Frequency of relevant sample data

	Frequency	%
Type of tooth		
Incisor	94	94.0
Canine	2	2.0
Premolar	3	3.0
Molar	1	1.0
Max incisor	87	87.0
Max canine	2	2.0
Max premolar	1	1.0
Mand incisor	7	7.0
Mand premolar	2	2.0
Mand molar	1	1.0
Type of non-surgical endodontic Tx		
Primary treatment	89	89.0
Secondary treatment	11	11.0
Reason for endodontic Tx		
Trauma	84	84.0
Caries	15	15.0
Non-vital/unknown	1	1.0
Apex status		
Mature	50	50.0
Immature	45	45.0
Resorbed	4	4.0
Obliterated	1	1.0
Treatment by staff grade		
Consultant	20	20.0
Middle grade	40	40.0
Junior grade	40	40.0

Table 3 Distribution of trauma by type of injury

Classification of trauma	Frequency	%
Enamel-dentine fracture	21	25.0
Complicated crown fracture	16	19.0
Crown root fracture	1	1.2
Complicated crown root fracture	3	3.6
Subluxation/concussion	8	9.5
Luxation	3	3.6
Extrusion	4	4.8
Intrusion	5	6.0
Avulsion	15	17.9
Dentoalveolar fracture	1	1.2
Unknown	7	8.3

sedation was the predominating form of anxiety control but its use produced no significant benefit in relation to the technical quality for this subpopulation ($p = 0.515$).

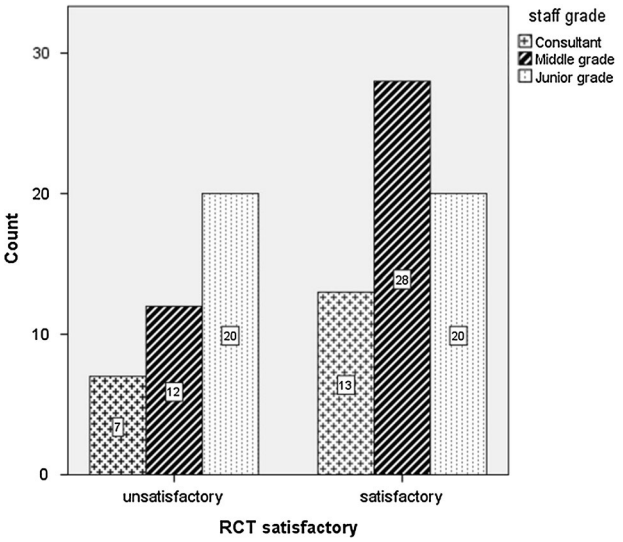

Fig. 1 Bar chart of treatment outcomes for different staff grades

Table 4 Frequency of obturation methods

	Frequency	%
Method of obturation		
Cold lateral condensation (CLC)	50	50.0
Matched point obturation (protaper only)	5	5.0
Thermal gutta percha (TGP)	41	41.0
Complete obturation with MTA or Biodentine	4	4.0
Voids produced in obturation method		
Cold condensed GP	18/55	32.7
Thermal GP/packable material	4/45	8.9

Length

Attaining length was not an issue with 81 % of obturations finishing within 2 mm of the anatomical apex. An electronic apex locator was used in 43 % of cases, however provided no significant benefit in ascertaining a suitable length ($p = 0.677$). Only one case was recorded as the canal being obliterated and in this instance the canal was negotiated to length. Interestingly the number of cases with extruded material was relatively equal between open (54.5 %) and closed (45.5 %) apices ($p = 0.697$), with no statistical difference in technical outcomes between apex status noted ($p = 0.236$).

Voids

The most common fault was the inclusion of voids during obturation. The frequency of obturation methods are summarised in Table 4. The use of thermal obturation materials produced a significant reduction in voids in

comparison to cold condensation techniques ($p = 0.004$), with a 5 times lower chance of voids occurring (OR 0.20, 95 % CI 0.06–0.65). This data is reflected when comparing the type of apexification method against voids in obturation. Again a statistical difference is noted when comparing calcium hydroxide to MTA ($p = 0.001$), however, apexification and obturation methods were frequently dependant variables.

Discussion

No comparable data available in the current literature specifically examines the technical quality of root canal treatment conducted on the permanent dentition in paediatric patients. This area of research is unique for two reasons; firstly children can be less co-operative and harder to manage, particularly over long periods of time and secondly, root canal configuration frequently differs from that of adult populations. Therefore, it is not suitable to compare this subpopulation to available data from adult studies.

One study examined the success of root treatments in first permanent molars of 8–16 years olds, demonstrating a 36 % success rate, but only a limited reference was made to the quality of treatment and the sample was not only small (28 root canal treatments), but also focused on first permanent molars (Peretz et al. 1997). A comparison to that study is therefore difficult, as the majority of teeth treated in the present study were anterior teeth. A number of studies focused on the management, prognosis and survival of traumatised teeth, although endodontic treatment was not conducted on every tooth and there is no commentary on the treatment quality (Wigen et al. 2008; Wriedt et al. 2010; Bücher et al. 2013). Additionally some data has been compiled to produce an online evidence-based reference for dental trauma (International Association of Dental Traumatology 2014).

In contrast to cases involving adults, dental caries rarely features as the causation for endodontic treatment in this study. Firstly caries is most likely to affect first permanent molars (Pitts and Harker 2003); these teeth are often extracted in young children due to their poor long term prognosis and chance of gaining a suitable orthodontic alignment if extracted at the appropriate time. Secondly, trauma frequently occurs in this age range and there is an increased risk of pulpal necrosis (depending upon the severity of injury, stage of root formation and treatment provided) (International Association of Dental Traumatology 2014). The findings of this study report a similar pattern of injury to previous studies where hard tissue fractures was more prevalent than displacement injuries in permanent teeth (Zaleckiene et al. 2014).

Open apices can complicate root canal treatment. With closed apices, modern electronic apex locators (EALs) have been considered the most accurate method of working length determination, partially due to the variability of apical constriction's position from the radiographical apex (Martins et al. 2014). In immature teeth root formation is incomplete and the minor and major apical foramina often do not exist in their usual form. Furthermore the rate at which dentine deposition occurs is often not equal in all planes.

Using modern EALs alone in immature teeth can be inaccurate. Firstly the lack of apical constriction can produce unreliable readings due to alterations in the tooth's capacitance (Nekoofar et al. 2006). Secondly the reliability of measurement in apices greater than ISO 80 has been demonstrated to be poor (although the majority of this data arises from simulated models of open apices) (Kim and Chandler 2013). Thirdly even though impedance ratio EALs are generally considered to be unaffected by intracanal electrolytes, excessive fluids (particularly blood) may affect the accuracy of readings (Kim and Chandler 2013).

A recent review examined the issues surrounding various methods of working length determination in open apices (Kim and Chandler 2013), concluding that radiographs and apex locators should be supplemented with alternative methods to determine a suitable measurement in open apices. This study did not show any relationship between length control and apex status even though it may be speculated that open apices are more likely to have extruded material. An alternative assessment method may be more appropriate if trying to detect this difference. In comparison to cone beam computed tomography, periapical radiographs have been shown to significantly misinterpret obturation length (Liang et al. 2012). Therefore, the current study may have an increased number of false negatives/positives.

Young and immature permanent teeth have large pulp chambers which require significant volumes of material to obturate. Of the obturations containing voids in this study, a high number were obturated using cold lateral condensation. Contrary to these findings, a recent meta-analysis concurred that the overall obturation qualities of warm GP vs cold lateral methods were similar (Peng et al. 2007). The results however were close to a statistical difference (RR = 1.31, 95 % CI 0.98–1.76, $p = 0.07$). Additionally the majority of studies included used adults and this information is less applicable to trauma in children due to differences in the size and shape of root canal systems. More time is required to obturate larger root canal volumes with cold lateral condensation (which could be adversely affected by child co-operation) and furthermore for irregular shaped canals injectable materials become more reliable (Natera et al. 2011). For these reasons it may be

proposed that thermal obturation should be the technique of choice in children.

All obturation material should be contained within the canal system but unfortunately extrusion is a common occurrence (Peng et al. 2007). In comparison to gutta percha, which has a negative effect on periradicular healing (Ricucci and Langeland 1998; Ng et al. 2011), MTA is not so detrimental. Calcium silicate derivatives have excellent biocompatibility and previous case reports have demonstrated the capability of bony infill around extruded MTA (Asgarya and Ehsanib 2012). Despite this healing does not occur every time and care should be taken when placing MTA to limit the material to the confines of the root canal as extrusion has been demonstrated to reduce success rates (Mente et al. 2013). The characteristics of MTA can make it a difficult material to work with and good control and visualisation are needed to prevent misplacement. MTA is recommended at a thickness of 3–4 mm to improve resistance form and mechanical properties (Malhotra et al. 2013). However, it may be proposed that as long as the remainder of the apex is sealed with an alternative obturation material, a plug of less that 3 mm is unlikely to affect the long term clinical outcome. Unfortunately no information could be found on this in the literature. Therefore, it may be appropriate to ignore this criterion in future studies assessing technical quality, as there is no evidence or scientific background to suggest MTA plugs <3 mm reduce success rates.

Although no statistical difference on technical outcome was noted between staff grades, a trend can be seen emerging to suggest junior staff have more unsatisfactory results compared with middle grades or consultants (Fig. 1). The study design was not designed towards assessing this question, which likely prevented a statistical significance occurring, but particularly when comparing the odds ratios of middle and junior grades shown in the graph (Fig. 1), a trend is visible. In the literature few studies comment on the influence of operator skill on technical quality, even though this variable may have been recorded (although not defined). Many clinicians would assume treatment quality and outcomes would improve with greater operator experience and skill. Available data concurs with this (Ng et al. 2011; Mente et al. 2013), particularly regarding to MTA placement (Mente et al. 2013). This statement is reinforced when comparing technical outcomes of general dental practitioners with specialist endodontists (Bierenkrant et al. 2008; Ertas et al. 2013; Di Filippo et al. 2014).

The influence of patient co-operation routinely affects which treatments can be performed on patients, particularly in children. Anxiety has previously been found to decrease patient attendance and compliance with dental procedures (Potter et al. 2014). The current study is in keeping with those previous findings, showing anxiety to produce the most negative effects. The use of sedation was not beneficial in modifying the outcome although due to sample size it would be unwise to assume this statement is absolute. Inhalation sedation is used routinely within dentistry but requires an element of patient maturity and co-operation to provide successful sedation. For patients who are hysterical the quantity of nitrous oxide inhaled will be lower so reducing the quality of sedation. Use of alternative methods, such as intravenous sedation (Wilson et al. 2003), could improve patient co-operation, but clinicians may not feel it appropriate for younger patients or prolonged treatments.

The debate of who is best to conduct this endodontic treatment is also relevant. One may argue an endodontist would be most appropriate, as these cases are often technically demanding. Conversely the behavioural management of these patients is often crucial to success and therefore paediatric dentists, who are regularly practised in both pharmacological and non-pharmacological anxiety control methods, may be more suited. It is the view of the authors' that, in the UK, specialist paediatric dentists are probably better set to holistically manage the patient throughout their care episode and with a little extra training and equipment, can produce a suitable standard of treatment.

The limitations of this study are recognised, namely retrospective study design, sample size and case selection bias. A larger sample size would have reduced the margin of error and confidence intervals and possibly identified more significant variables. The sample was drawn from one tertiary institution, therefore, it is likely that case selection bias was introduced, yet chronological cases where chosen to try to ensure a good case mix whilst maintaining examination of modern treatment methods. Unfortunately extrapolation of this information to a wider population is therefore limited; however, some valuable information was identified. The authors recognise the lack of follow-up data pertaining to the endodontic treatment provided. Success data is invaluable information for the planning of patients' long term management, particularly with young children where growth is still occurring and a multidisciplinary approach may be necessary. However, technical quality is a risk factor for endodontic success and although quality of treatment alone does not substitute for good long term outcome data; it does underpin many clinicians' decision making process when trying to predict success on an individual basis. This study provides the first information for Paediatric Dentists regarding factors affecting the technical outcomes of endodontic treatment in children.

Conclusion

The overall technical quality of orthograde endodontic treatment in the examined subpopulation is comparative to the higher limits of endodontics conducted in the general

population. A number of variables and trends that affect outcomes have been identified, namely that anxiety in particular has a negative impact on root canal quality and thermal obturation techniques may be superior to cold lateral condensation for obturation in children with wide canals.

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Conflict of interest The Authors have no conflicts of interest to declare.

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