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REVIEW

Outcome of primary root canal treatment: systematic review of the literature – Part 1. Effects of study characteristics on probability of success

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Abstract

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Aims The aims of this study were (i) to conduct a comprehensive systematic review of the literature on the outcome of primary (initial or first time) root canal treatment; (ii) to investigate the influence of some study characteristics on the estimated pooled success rates.

Methodology Longitudinal clinical studies investigating outcome of primary root canal treatment, published up to the end of 2002, were identified electronically (MEDLINE and Cochrane database 1966–2002 December, week 4). Four journals (International Endodontic Journal, Journal of Endodontics, Oral Surgery Oral Medicine Oral Pathology Endodontics Radiology and Dental Traumatology & Endodontics), bibliographies of all relevant papers and review articles were hand-searched. Three reviewers (Y-LN, SR and KG) independently assessed, selected the studies based on specified inclusion criteria, and extracted the data onto a pre-designed proforma. The study inclusion criteria were: longitudinal clinical studies investigating root canal treatment outcome; only primary root canal treatment carried out on the teeth studied; sample size given; at least 6-month postoperative review; success based on clinical and/or radiographic criteria (strict, absence of apical radiolucency; loose, reduction in size of radiolucency); overall success rate given or could be calculated from the raw data. The findings by individual study were summarized and the pooled success rates by each potential influencing factor were calculated for this part of the study.

Results Of the 119 articles identified, 63 studies published from 1922 to 2002, fulfilling the inclusion criteria were selected for the review: six were randomized trials, seven were cohort studies and 48 were retrospective studies. The reported mean success rates ranged from 31% to 96% based on strict criteria or from 60% to 100% based on loose criteria, with substantial heterogeneity in the estimates of pooled success rates. Apart from the radiographic criteria of success, none of the other study characteristics could explain this heterogeneity. Twenty-four factors (patient and operative) had been investigated in various combinations in the studies reviewed. The influence of preoperative pulpal and periapical status of the teeth on treatment outcome were most frequently explored, but the influence of treatment technique was poorly investigated.

Conclusions The estimated weighted pooled success rates of treatments completed at least 1 year prior to review, ranged between 68% and 85% when strict criteria were used. The reported success rates had not improved over the last four (or five) decades. The quality of evidence for treatment factors affecting primary root canal treatment outcome is sub-optimal; there was substantial variation in the study–designs. It

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would be desirable to standardize aspects of study–design, data recording and presentation format of outcome data in the much needed future outcome studies.

Keywords: outcome, root canal treatment, success, systematic review.

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Introduction

There has been a surge of interest in formulating clinical guidelines for optimal treatment of diseases based on properly conceived and executed research. The gold standard for informing clinical practice is putatively the randomized controlled trial (RCT); however, neither medical nor dental practice has been generally well supported by such evidence. Sackett *et al.* (1996) now famous definition, 'the conscientious, explicit and judicious use of current best evidence in making decisions about the care of individual patients', not only embraces the notion of grades of evidence but also recognizes that optimal levels of evidence may not be available for all situations. There is therefore a need to synthesize an objective over-view based on *available* evidence. Depending upon the quality and quantity of the data, systematic reviews can be of several different kinds: traditional reviews; meta-analysis leading to an estimate of effect size; best evidence synthesis; and the hypothetico-deductive approach, in which the effort is directed at evaluating the evidence for and against a given theory, in an attempt to solve the problem of why contradictory results appear, rather than simply averaging often incompatible data (Eysenck 1994).

For the outcome of endodontic treatment, there are eight published systematic reviews, which have used different approaches in synthesis of information from the literature. Basmadjian-Charles *et al.* (2002) and Paik *et al.* (2004) used a systematic approach for literature search but a traditional approach for evaluating the variables impacting on the success and failure of the root canal retreatment. Two reviews (Hepworth & Friedman 1997, Peterson & Gutmann 2001) calculated the weighted-average success rates by each factor under investigation. Neiderman & Theodosopoulou (2003) estimated the number needed to treat when comparing two types of treatments. Three reviews (Lewsey *et al.* 2001, Kojima *et al.* 2004, Sathorn *et al.* 2005) estimated the size of effect of individual factors which included presence of preoperative pulpal and periapical status, apical extent of root filling & number of treatment visits, using meta-analysis. Except for Lewsey *et al.* (2001), none have investigated the influence of study characteristics such as radiographic criteria for determination of treatment outcome and year of publication, on the data heterogeneity.

In the absence of sufficient gold standard level data, there is a need to synthesize 'sub-standard' data but there is a lack of formal guidelines to achieve this. In the absence of such guidelines, the authors proposed the use of a process of 'triangulation' of different analytical approaches as a sensible strategy. The purpose of this systematic review and synthesis was to: (i) identify the probable dominant factors influencing outcome; (ii) help prioritize the questions that need to be addressed; (iii) inform the design and data collection protocol for future RCTs. The outcome of this analysis will be presented in two parts.

The aim of the first part of this paper is to present the estimated pooled success rates of primary root canal treatment by aspects of study characteristics: decade of publication, study-specific criteria for success, unit of outcome measure, duration after treatment, geographical location of study and qualification of the operator.

Materials and methods

Literature search

Longitudinal clinical studies investigating the outcome of primary root canal treatment that were published up to the end of 2002 were identified electronically (MEDLINE database 1966–2002 December, week 4) using six keywords (root canal treatment, root canal therapy, endodontic treatment, endodontics, treatment outcome and success) and eight strategies (1 AND 5, 1 AND 6, 2 AND 5, 2 AND 6, 3 AND 5, 3 AND 6, 4 AND 5 and 4 AND 6). A Cochrane Library search was also conducted. PubMed was independently searched using the 'related articles' feature. Four journals (International Endodontic Journal, Journal of Endodontics, Oral Surgery Oral Medicine Oral Pathology Endodontics Radiology and Dental Traumatology & Endodontics) and bibliographies of all relevant papers and review articles were hand-searched. Unpublished studies were identified by searching abstracts and conference proceedings. Personal contacts were also used to identify ongoing or unpublished studies. Full articles were obtained for all relevant titles identified through either electronic or other search methods.

Study selection, quality assessment and data extraction

Three reviewers (Y-LN, SR and KG) independently assessed and selected the studies based on the following inclusion criteria:

1. Clinical study on primary root canal treatment.
2. Stratified analysis of primary root canal treatment available, if root canal re-treatment cases had been included.
3. Sample size given.
4. At least 6-month postoperative review.
5. Success based on clinical and/or radiographic (strict, absence of apical radiolucency; loose, reduction in size of radiolucency) criteria.
6. Overall success rate given or could be calculated from the raw data.
7. Presentations in English, German, Chinese and Japanese languages were accepted.

Disagreements on study inclusion were resolved by discussion. The reasons for study rejection at this or subsequent stages were recorded.

Data were extracted by all three reviewers independently using custom-designed data collection forms. The data collection form was piloted on several papers and modified for optimal utility before final use. The data extracted could be classified into six groups; success rates, study characteristics, demographic data of patients, pre-, intra- and postoperative factors. Any disagreement was discussed and data were excluded if agreement could not be reached.

Estimation of pooled success rates

STATA version 9.2 statistical software (StataCorp, College Station, TX, USA) was used to perform all statistical analyses. Un-weighted pooled success rate by each factor was calculated by dividing the total number of successful units with the total number of units within the respective category (according to Hepworth & Friedman 1997). In addition, the weighted pooled success rates were estimated using random effects meta-analysis with DerSimonian and Laird's methods (DerSimonian & Laird 1986). Statistical heterogeneity amongst the studies was assessed by Cochran's (Q) test (Cochran 1954).

Meta-regression models (Thompson & Higgins 2002) were used to explore the potential sources of statistical heterogeneity and to assess the effect of factors on estimating the pooled success rate. Factors related with study characteristics considered in the meta-regression analyses as covariates (and their sub-categories) were: decade of publication, study specific criteria (radiographic, combined radiographical & clinical) for success, unit of outcome measure (tooth and root), duration after treatment when assessing success ('at least 4 years' or '<4 years'), geographical location of the study (North American, Scandinavian and other countries), qualification of the operator (undergraduate students, postgraduate students, general dental practitioners (GDP), specialist or mixed group). If either the estimated proportion of total variation because of heterogeneity across studies (I^2) or the estimated between-study variance (τ^2) from the meta-regression model without covariate in the model was reduced substantially (>10%) when a covariate was included into the model, the respective covariate was considered to be a potential source of heterogeneity.

Results

A total of 119 papers were identified in the initial search, 51 articles were excluded for the reasons given in Table 1. Some papers presented different parts of the same study, so their data were combined for analyses in this review: (i) Heling & Tamshe (1970, 1971); (ii) Barbakow *et al.* (1980a,b, 1981); (iii) Morse *et al.* (1983a,b,c); (iv) Ørstavik *et al.* (1987) & Eriksen *et al.* (1988). Conversely, Kerekes (1978) presented two separate data sets in their paper, and were therefore considered as two separate studies in this review. As a result, 63 studies fulfilling the inclusion criteria were selected for this review. The year of publication of the selected studies ranged from 1922 to 2002 with the highest number of studies published in the 1980s ($n = 16$) (Table 2).

Each reviewer had entered 174 data points per selected study and the initial agreements amongst the three reviewers were moderate ($\kappa = 0.57$–0.61). As per protocol, following discussion about any disagreements, there was 100% concurrence on used data.

Methodological characteristics of included studies

Of the 63 studies included in this review, six were RCTs (Table 2). Others were cohort studies ($n = 8$) or retrospective observational studies ($n = 49$). Although

Table 1 Reasons for exclusion of the 51 articles

Article	Inclusion criteria (1–6) not fulfilled or other reasons for exclusion
Grove (1921)	[1]Clinical study for primary root canal treatment
Hinman (1921)	[3]Sample size given
	[6]Overall success rate given or could be calculated
Grove (1923)	[1]Clinical study for primary root canal treatment
Coolidge (1926)	[6]Overall success rate given or could be calculated
Rhein *et al.* (1926)	[4]At least 6-month postoperative review
Puterbaugh (1926)	[3]Sample size given
	[6]Overall success rate given or could be calculated
Hall (1928)	[1]Clinical study for primary root canal treatment
Appleton (1932)	[4]At least 6-month postoperative review
Buchbinder (1936)	[2]Stratified analysis available
Macphee (1936)	[6]Overall success rate given or could be calculated
Strindberg (1956)	[2]Stratified analysis of one RCT available
Frostell (1963)	[2]Stratified analysis of one RCT available
Nichols (1963)	[1]Clinical study for primary root canal treatment
Grossman *et al.* (1964)	[2]Stratified analysis of one RCT available
Engström *et al.* (1964)	[2]Stratified analysis of one RCT available
Ingle *et al.* (1965)	[2]Stratified analysis of one RCT available
Curson (1966)	[1]Clinical study for primary root canal treatment
Oliet & Sorin (1969)	[5]Success based on clinical and/or radiographic criteria
Storms (1969)	[2]Stratified analysis of one RCT available
Ratliff (1973)	[5]Success based on clinical and/or radiographic criteria
Cvek *et al.* (1976)	[2]Stratified analysis of one RCT available
Adenubi (1978)	Same data set as Adenubi & Rule (1976)
Taintor *et al.* (1978)	[1]Clinical study for primary root canal treatment
Vernieks & Messer (1978)	[2]Stratified analysis of one RCT available
Kerekes & Tronstad (1979)	[2]Stratified analysis of one RCT available
Markitziu & Heling (1981)	[1]Clinical study for primary root canal treatment
Hession (1981)	[2]Stratified analysis of one RCT available
Thoden van Velzen *et al.* (1981)	Same data set as Kerekes & Tronstad (1979)
Ashkenaz (1984)	[5]Success based on clinical and/or radiographic criteria
Seto *et al.* (1985)	[5]Success based on clinical and/or radiographic criteria
Ørstavik *et al.* (1986)	[6]Overall success rate given or could be calculated
Teo *et al.* (1986)	[2]Stratified analysis of one RCT available
Kullendorff *et al.* (1988)	[1]Clinical study for primary root canal treatment
Molven & Halse (1988)	[2]Stratified analysis of one RCT available
	Same data set as Halse & Molven (1987)
Augsburger & Peters (1990)	[4]At least 6-month postoperative review
	[5]Success based on clinical and/or radiographic criteria
Stabholz (1990)	[1]Clinical study for primary root canal treatment
Wong *et al.* (1992)	[5]Success based on clinical and/or radiographic criteria
Ørstavik & Hörsted-Bindslev (1993)	[6]Overall success rate given or could be calculated
Gutknecht *et al.* (1996)	[4]At least 6-month postoperative review
Friedman (1997)	[1]Clinical study for primary root canal treatment
Ricucci & Langeland (1997)	[1]Clinical study for primary root canal treatment
Weine & Buchanan (1997)	[1]Clinical study for primary root canal treatment
Shi *et al.* (1997)	[5]Success based on clinical and/or radiographic criteria
Weiger *et al.* (1998)	[1]Clinical study for primary root canal treatment
Caplan & White (2001)	[5]Success based on clinical and/or radiographic criteria
Oliver & Abbott (2001)	[1]Clinical study for primary root canal treatment
Waltimo *et al.* (2001)	[6]Overall success rate given or could be calculated
Lazarski *et al.* (2001)	[5]Success based on clinical and/or radiographic criteria
Lynch *et al.* (2002)	[5]Success based on clinical and/or radiographic criteria
Caplan *et al.* (2002)	[5]Success based on clinical and/or radiographic criteria
Murakami *et al.* (2002)	[4]At least 6-month postoperative review

nine studies (Grahnén & Hansen 1961, Storms 1969, Selden 1974, Heling & Kischinovsky 1979, Pekruhn 1986, Sjögren *et al.* 1990, Friedman *et al.* 1995, Chugal *et al.* 2001, Hoskinson *et al.* 2002) had included previously root-filled teeth in their sample, they had provided stratified analysis for primary treatment.

The recall rates (percentage of patients attending for follow-up after treatment) were reported by 39 studies and ranged from 11% to 100% with a median of 52.7%. Either root (27 studies) or tooth (36 studies) was used as the unit of outcome measure. The sample sizes ranged from 22 to 2921 teeth or 38 to 2921 roots; some studies only included single-rooted teeth, hence the number of teeth and roots were the same.

The treatment outcome was determined by radiographic examination alone (27 studies) or in combination with clinical findings (36 studies) (Table 2). Different radiographic criteria of success have been used and these were divided into: 'strict' (complete resolution of peri-apical lesion at recall) or 'loose' (reduction in size of existing peri-apical lesion at recall). For the radiographic assessment of the outcome of treatment, only 19 studies (Table 2) employed at least two observers to carry out the assessment. Observer(s) were calibrated prior to evaluation of radiographs in eight studies and intra- or inter-observer reliability tests were carried out in nine studies (Table 2).

Different studies have evaluated the influence of a range of different clinical prognostic factors on outcome but the combinations of factors reported vary (Table 3). The statistical methods used for analysing the association between potential influencing factors and treatment outcome were the chi-square test (31 studies), relative incidence distribution (two studies), logistical regression models (three studies), ANOVA (two studies), survival analysis (one study) and logistic regression models using generalized estimating equations (one study) (Table 2). Twenty-three studies did not analyse the data statistically or did not present such information.

Success rates by study characteristics

Outcome measure used

The reported success rates of root canal treatment ranged from 31% to 96% based on strict criteria and from 60% to 100% based on loose criteria. The weighted pooled success rates from studies using 'strict' criteria (data available from 40 studies) were about 10% lower than those from studies using 'loose' criteria (data available from 38 studies) regardless of examination method used (Table 4). Some studies ($n = 14$) presented the success rates stratified by both strict and loose criteria.

After combining the data from the two examination methods, the pooled success rates estimated by meta-analyses were 74.7% (95% CI: 69.8–79.5%) from 40 studies using strict radiographic criteria and 85.2% (95% CI: 82.2–88.3%) from 36 studies using loose radiographic criteria. The estimated success rates by individual studies as well as the weighted pooled success rates by the two radiographic criteria are presented as Forrest plots in Figs 1 and 2. Meta-regression analyses showed the reported success rates based on strict radiographic criteria were 10.5% (4.4–16.7%, $P = 0.001$) lower than the success rates based on loose radiographic criteria. The radiographic criteria were also found to be responsible for part of the statistical heterogeneity, therefore the estimated success rates by individual factors were calculated separately for data based on the use of strict or loose criteria.

Duration after treatment completion

Most studies did not standardize the duration after treatment completion when the outcomes were reviewed, which ranged from 6 months to 30 years. Only 15 studies (Table 2) followed-up all the cases for at least 4 years. Attempts to pool data on success rates by different follow-up durations are confounded by the relatively small study numbers in some groups and may have produced distorted results. When strict criteria were used, the pooled success rates increased with longer follow-ups; the substantial increases were between 6 and 12 months and between 24 and 36 months after treatment (Table 4). However, there was no obvious trend in success rate by duration after treatment when loose criteria were used.

Year of publication

The pooled success rates based on 'loose' outcome criteria for each decade since the 1920s appeared to be similar with the highest pooled success rate at 88.2% during the 1980s (Table 4). However, the pooled success rates based on 'strict' outcome criteria for studies published during 1960s (79.7%) and 1970s (79.0%) were the highest. More importantly, the expected trend of progressively increasing success rates over the last century was clearly not in evidence.

Geographical location of study

About one-third of the studies were carried out in the USA or Canada (24 studies) and the rest were carried

Table 2 Study characteristics

Author (year)	Geographic location of study	[a]Study–design	Recall rate (%)	≥4 year follow-up after treatment	[b]Unit of measure	Sample size	[c]Assessment of success	[d]Radiographic criteria of success	≥2 radiographic observers	Calibration	Reliability test	[e]Statistical analysis
Blayney (1922)	USA	R	28		T	104	C&R	L				
Auerbach (1938)	USA	R	22		T	211	C&R	L				
Buchbinder (1941)	USA	R	–		Ro	245	Ra	S				
Morse & Yates (1941)	USA	R	–		T	265	Ra	L				
Castagnola & Orlay (1952)	Scandinavia	R	68		T	1000	C&R	S				
Grahnén & Hansen (1961)	Scandinavia	R	44	✔	Ro	1277	C&R	S	✔			
Seltzer *et al.* (1963)	USA	C	–		Ro	2921	Ra	L				
Zeldow & Ingle (1963)	USA	C	–		T	42	C&R	L				
Bender *et al.* (1964)	USA	R	30		Ro	706	Ra	L	✔			
Engström & Lundberg (1965)	Scandinavia	R	74		Ro	181	Ra	S				
Harty *et al.* (1970)	UK	R	60		Ro	1139	C&R	S				χ^2
Heling & Tamshe (1970, 1971)	Israel	R	27		T	213	C&R	S				
Cvek (1972)	Scandinavia	R	–		Ro	55	Ra	S				ANOVA
Selden (1974)	USA	R	11		T	556	Ra	L				χ^2
Werts (1975)	USA	R	23	✔	T	47	C&R	S				
Adenubi & Rule (1976)	UK	R	–		Ro	870	C&R	S				χ^2
Heling & Shapira (1978)	Israel	R	17		T	118	C&R	S				
Jokinen *et al.* (1978)	Scandinavia	R	45		Ro	2459	C&R	S	✔			χ^2
Kerekes (1978)	Scandinavia	R	–		Ro	379	Ra	S	✔			χ^2
Kerekes (1978)	Scandinavia	R	–		Ro	188	Ra	S	✔			χ^2
Soltanoff (1978)	USA	R	–		T	266	Ra	L				
Heling & Kischinovsky (1979)	Switzerland	R	13		Ro	202	C&R	L				χ^2
Barbakow *et al.* (1980a,b, 1981)	South Africa	R	60		T	335	C&R	L				χ^2
Cvek *et al.* (1982)	Scandinavia	R	83	✔	Ro	45	Ra	S				χ^2
Nelson (1982)	UK	R	–		T	299	C&R	L				χ^2
Boggia (1983)	UK	R	–		T	52	Ra	S				
Klevant & Eggink (1983)	Holland	R	76		T	319	Ra	S				χ^2
Morse *et al.* (1983a,b,c)	USA	R	–		Ro	458	C&R	L				χ^2
Oliet (1983)	USA	C	–		T	338	C&R	L				χ^2
Swartz *et al.* (1983)	USA	R	–		Ro	1770	C&R	L				χ^2
Pekruhn (1986)	Saudi Arabia	R	81		T	925	C&R	S				χ^2
Byström *et al.* (1987)	USA	C	56		Ro	79	Ra	S	✔			χ^2
Halse & Molven (1987)	Scandinavia	R	63	✔	Ro	551	Ra	S				χ^2
Matsumoto *et al.* (1987)	Japan	R	38		T	85	C&R	L				χ^2
Ørstavik *et al.* (1987) & Eriksen *et al.* (1988)	Scandinavia	RCT	36	✔	Ro	289	Ra	L		✔	✔	RIDIT
Safavi *et al.* (1987)	USA	R	–		T	464	C&R	S	✔	✔	✔	χ^2

Akerblom & Hasselgren (1988)	Scandinavia	R	73		Ro	64	C&R	S	✔			
Shah (1988)	India	C	70		T	65	C&R	L				
Sjögren *et al.* (1990)	Scandinavia	R	46	✔	Ro	573	Ra	S	✔	✔	✔	LR
Murphy *et al.* (1991)	USA	R	–		T	89	Ra	S				
Cvek (1992)	Scandinavia	R	76	✔	Ro	610	Ra	S				χ^2
Reid *et al.* (1992)	Australia	RCT	44	✔	Ro	74	C&R	S	✔			χ^2
Jurcak *et al.* (1993)	USA	R	58		T	102	C&R	L	✔			
Smith *et al.* (1993)	UK	R	54	✔	T	821	C&R	L				χ^2
Peak (1994)	UK	R	–		T	136	C&R	S			✔	χ^2
Friedman *et al.* (1995)	Canada	C	78		T	250	C&R	S				χ^2
Çalişken & Şen (1996)	Turkey	R	–		T	172	C&R	S				
Østavik (1996)	Scandinavia	C	81	✔	Ro	599	Ra	L		✔	✔	RIDIT
Peretz *et al.* (1997)	Israel	R	–		T	28	C&R	S				χ^2
Sjögren *et al.* (1997)	Scandinavia	C	96	✔	Ro	53	Ra	S	✔	✔		
Lilly *et al.* (1998)	USA	R	–		T	22	C&R	S	✔			
Trope *et al.* (1999)	USA	RCT	–		T	102	Ra	S	✔	✔	✔	χ^2
Ricucci *et al.* (2000)	Italy	R	–		T	110	Ra	S	✔			χ^2
Weiger *et al.* (2000)	Germany	RCT	92		T	67	C&R	S	✔			LR
Chugal *et al.* (2001)	USA	R	75	✔	R	322	Ra	S	✔			LR
Deutsch *et al.* (2001)	USA	R	42		T	153	C&R	L				χ^2
Heling *et al.* (2001)	Israel	R	–		T	319	Ra	L				ANOVA
Peak *et al.* (2001)	UK	R	–	✔	T	406	C&R	L			✔	
Pettiette *et al.* (2001)	USA	RCT	66		T	40	Ra	L				χ^2
Benenati & Khajotia (2002)	USA	R	29		T	894	Ra	S				χ^2
Cheung (2002)	Hong Kong	R	28	✔	T	282	C&R	S				Survival
Hoskinson *et al.* (2002)	UK	R	42	✔	Ro	413	C&R	S	✔	✔	✔	GEE
Peters & Wesselink (2002)	Holland	RCT	100		Ro	38	C&R	S	✔	✔	✔	χ^2

[a]R, retrospective study; C, prospective cohort study; RCT, randomized controlled trial.
[b]T, teeth; Ro, root (unit of measure was recorded as 'root' for those studies which has only included single rooted teeth in their sample).
[c]C&R, combined clinical and radiographic examination; Ra, radiographic examination only.
[d]S, strict criteria; L, loose criteria.
[e]LR, single level logistic regression; GEE, generalized estimating equations; χ^2, chi-squared test; RIDIT, relative incidence distribution; ANOVA, analysis of variance; Survival, survival analysis.

Table 3 Clinical prognostic factors included in studies

Author (year)	Gender	Age	Health	Tooth type	Pulpal status	Periapical status	Lesion size	Rubber dam	Obstruction	Apical size	Canal taper	Irrigant	Medicament	Culture test	RF material technique	Sealer	RF extent	Quality of RF	Acute flare up	Apical disturbance	Visits of treatment	Restoration	Abutment
Blayney (1922)					✔	✔		✔				✔											
Auerbach (1938)					✔	✔						✔											
Buchbinder (1941)					✔	✔		✔				✔	✔	✔							✔		
Morse & Yates (1941)					✔	✔		✔				✔		✔							✔		
Castagnola & Orlay (1952)					✔	✔		✔													✔		
Grahnén & Hansen (1961)					✔	✔						✔			✔		✔				✔		
Seltzer *et al.* (1963)		✔			✔	✔								✔	✔		✔						
Zeldow & Ingle (1963)								✔				✔		✔	✔						✔		
Bender *et al.* (1964)					✔	✔								✔	✔		✔				✔		
Engström & Lundberg (1965)					✔								✔	✔							✔		
Harty *et al.* (1970)		✔						✔				✔					✔	✔		✔	✔		
Heling & Tamshe (1970, 1971)					✔	✔		✔				✔	✔			✔	✔						
Cvek (1972)					✔	✔		✔				✔		✔							✔		
Selden (1974)					✔	✔	✔																
Werts (1975)					✔	✔																	
Adenubi & Rule (1976)	✔	✔		✔	✔	✔						✔	✔		✔	✔	✔	✔		✔	✔		
Heling & Shapira (1978)					✔	✔		✔					✔	✔	✔	✔	✔				✔	✔	
Jokinen *et al.* (1978)	✔	✔		✔	✔	✔							✔		✔		✔				✔		✔
Kerekes (1978)				✔											✔		✔	✔					
Kerekes (1978)				✔				✔							✔		✔	✔					
Soltanoff (1978)												✔			✔		✔				✔		
Heling & Kischinovsky (1979)					✔	✔		✔				✔	✔		✔	✔	✔						
Barbakow *et al.* (1980a,b, 1981)		✔		✔	✔	✔		✔					✔		✔	✔	✔				✔		
Cvek *et al.* (1982)					✔	✔		✔	✔			✔			✔								
Nelson (1982)		✔			✔	✔										✔	✔	✔		✔			
Boggia (1983)					✔	✔										✔	✔			✔	✔		
Klevant & Eggink (1983)								✔				✔	✔			✔	✔						
Morse *et al.* (1983a,b,c)					✔	✔						✔	✔		✔		✔				✔		
Oliet (1983)	✔	✔			✔	✔						✔			✔	✔	✔				✔		
Swartz *et al.* (1983)	✔	✔		✔		✔									✔		✔					✔	
Pekruhn (1986)					✔	✔		✔				✔				✔					✔		
Byström *et al.* (1987)					✔	✔		✔						✔	✔		✔				✔		
Halse & Molven (1987)					✔	✔									✔		✔						
Matsumoto *et al.* (1987)					✔	✔	✔	✔					✔	✔			✔				✔		✔

Ørstavik *et al.* (1987) & Eriksen *et al.* (1988)					✔	✔						✔											
Safavi *et al.* (1987)					✔	✔						✔		✔	✔	✔					✔	✔	
Akerblom & Hasselgren (1988)					✔	✔	✔	✔	✔			✔	✔		✔						✔		
Shah (1988)					✔	✔		✔							✔	✔					✔		
Sjögren *et al.* (1990)				✔	✔	✔	✔	✔				✔		✔	✔		✔	✔			✔		
Murphy *et al.* (1991)					✔	✔																	
Cvek (1992)					✔	✔									✔		✔				✔		
Reid *et al.* (1992)								✔					✔		✔	✔					✔		
Jurcak *et al.* (1993)				✔											✔						✔		
Smith *et al.* (1993)	✔	✔			✔	✔		✔			✔				✔	✔	✔				✔		
Peak (1994)				✔	✔	✔									✔		✔						
Friedman *et al.* (1995)					✔	✔						✔	✔		✔	✔							
Çalişken & Şen (1996)			✔		✔	✔	✔	✔				✔	✔		✔	✔				✔	✔		
Østavik (1996)					✔	✔		✔				✔											
Peretz *et al.* (1997)		✔			✔	✔																	
Sjögren *et al.* (1997)					✔	✔		✔				✔		✔	✔						✔		
Lilly *et al.* (1998)			✔		✔	✔									✔	✔						✔	
Trope *et al.* (1999)			✔					✔				✔	✔		✔	✔					✔		
Ricucci *et al.* (2000)								✔				✔			✔							✔	
Weiger *et al.* (2000)					✔	✔		✔				✔	✔		✔	✔					✔		
Chugal *et al.* (2001)					✔																		
Deutsch *et al.* (2001)					✔			✔				✔			✔	✔					✔		
Heling *et al.* (2001)					✔	✔						✔				✔	✔	✔				✔	
Peak *et al.* (2001)				✔	✔	✔									✔		✔						
Pettiette *et al.* (2001)					✔	✔																	
Benenati & Khajotia (2002)	✔	✔		✔												✔							
Cheung (2002)	✔	✔		✔	✔	✔		✔					✔		✔	✔					✔		
Hoskinson *et al.* (2002)	✔	✔		✔	✔	✔	✔	✔		✔	✔	✔	✔			✔	✔					✔	
Peters & Wesselink (2002)			✔		✔	✔		✔				✔	✔	✔	✔	✔					✔	✔	
Total	8	13	4	13	51	49	6	33	2	1	2	32	20	14	38	25	29	7	0	5	35	8	2

RF, root filling.

Table 4 Estimated success rates by study characteristics

Factor/categories	[a]No. studies identified	Strict radiographic criteria				Loose radiographic criteria			
		No. studies	No. units	Estimated pooled success rates		No. studies	No. units	Estimated pooled success rates	
				[c]Un-weighted (%)	[d]Weighted (%)			[c]Un-weighted (%)	[d]Weighted (%)
Outcome measure used									
Radiographic	27	17	4745	74.4	74.1 (66.9–81.3)	14 (13)[b]	7177	83.4	84.1 (79.0–89.3)
Clinical + radiographic	36	23	10799	72.8	75.0 (68.4–81.7)	24 (23)[b]	10430	82.0	85.8 (81.8–89.9)
Duration after treatment (months)									
6	4	2	1120	17.3	29.6 (14.2–73.3)	2	4633	89.1	89.1 (78.8–99.5)
12	9	5	2080	68.6	67.7 (39.0–96.4)	4	798	76.7	69.5 (52.3–86.6)
24	6	3	2328	75.8	67.3 (43.8–90.9)	3	1103	82.7	82.5 (75.2–89.8)
36	5	2	941	80.4	80.6 (78.0–83.1)	3	254	69.3	66.6 (36.1–95.9)
48	6	5	2931	84.5	83.8 (79.3–88.3)	2	301	93.5	61.7 (25.0–96.0)
>48	9	8	1162	86.8	85.4 (80.3–90.6)	1	821	84.3	84.3 (81.8–86.8)
Year of publication									
Before 1960	5	2	1245	68.2	68.2 (65.6–70.8)	4	1580	82.2	84.2 (72.2–96.1)
1960s	5	2	1458	81.3	79.7 (74.0–85.4)	3	3669	80.4	80.4 (79.2–81.7)
1970s	12	9	5468	69.8	79.0 (66.7–91.3)	6 (5)[b]	4400	77.0	84.0 (71.3–96.6)
1980s	16	9	2834	77.8	74.8 (62.5–87.0)	10 (9)[b]	3770	89.7	88.2 (85.0–91.4)
1990s	14	10	2007	83.9	76.9 (69.7–84.1)	8	2271	83.3	85.5 (80.2–90.9)
2000s	11	8	2532	65.2	68.0 (60.5–75.4)	7	1917	85.2	85.1 (78.0–92.3)
Geographic location of study									
USA or Canada	24	9	2412	67.5	74.1 (64.9–83.2)	20 (19)[b]	9393	86.5	88.1 (84.9–91.2)
Scandinavian country	15	12	6435	71.5	80.5 (71.1–89.8)	3 (2)[b]	3347	70.4	70.3 (61.3–79.2)
Other country	24	19	6697	76.9	71.2 (64.4–78.1)	15	4867	83.4	84.5 (80.4–88.5)
Qualification of operators									
Undergraduate students	21	14	8306	68.4	74.8 (67.0–82.7)	11 (10)[b]	7808	79.9	83.3 (75.8–90.9)
GDP	7	6	1353	64.4	65.7 (56.3–75.1)	5	1228	85.5	86.2 (82.9–89.5)
Postgraduate students	4	4	1336	82.9	77.2 (64.5–89.8)	2	959	93.1	93.1 (91.5–94.7)
Specialist	23	11	3288	87.6	84.8 (80.1–89.4)	17 (16)[b]	6368	84.7	87.6 (83.9–91.3)

GDP, general dental practitioners.

[a]Total number of studies identified for the respective study characteristics is equal to or smaller than the summation of number of studies under strict and loose criteria as some studies reported success rates based on both criteria.

[b]Number in bracket indicating the number of studies included in the meta-analysis after those studies with 100% rates by the respective factor under investigation have been excluded.

[c]Un-weighted pooled success rates were estimated based on the Hepworth & Friedman (1997)'s approach.

[d]Weighted pooled success rates were estimated using random effects meta-analysis (where there was only one study, its reported success rate and confident intervals were presented).

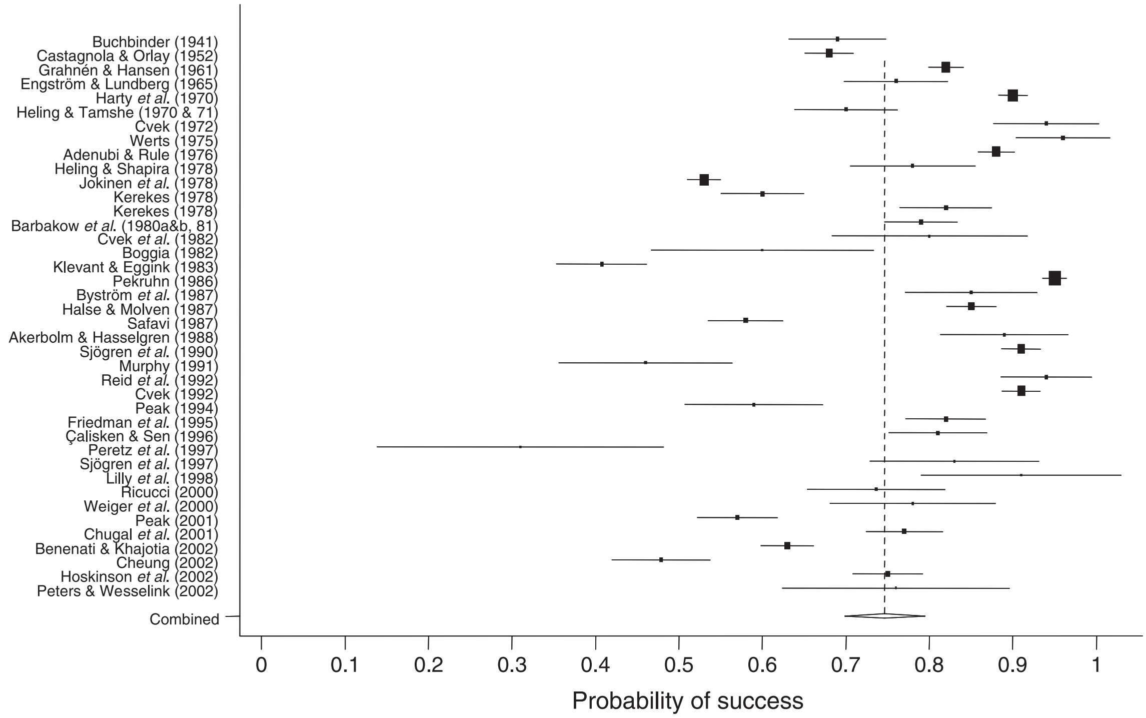

Figure 1 Probability of success based on strict radiographic criteria.

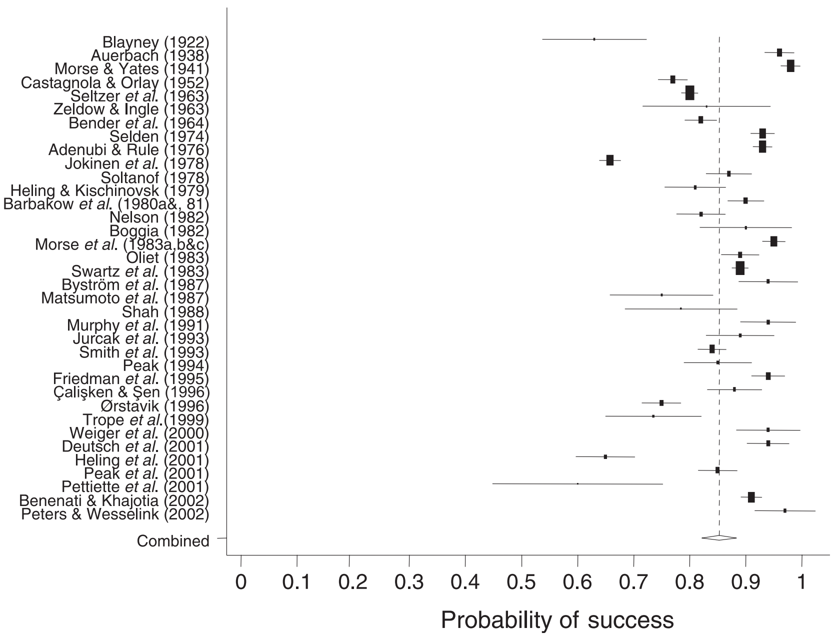

Figure 2 Probability of success based on loose radiographic criteria.

out in Scandinavian (15 studies, Sweden/Norway) or other countries (24 studies) including: UK (eight studies), Israel (four studies), Holland (two studies), Switzerland (one study), Australia (one study), Germany (one study), Hong Kong (one study), India (one study), Italy (one study), Japan (one study), Saudi

Arabia (one study), South Africa (one study) and Turkey (one study) (Table 2). The studies performed in the North American countries reported the treatment outcome data more frequently based on loose radiographic criteria than on strict criteria. In contrast, most of the outcome data from the Scandinavian countries were based on strict rather than loose criteria. Based on the loose criteria, the pooled estimate of success rate of treatment carried out in Scandinavian countries (70.3%) was much lower than for those in North American (88.1%) or other (84.5%) countries; however, the pooled estimate for the Scandinavian countries, only consisted of two studies. In stark contrast, the pooled estimate of success rate from outcome data based on strict criteria from the Scandinavian countries (80.5%) was the highest (Table 4).

Qualification of operators (undergraduate, postgraduate, GDP and specialist)

Only two studies compared the outcome of root canal treatment by qualification of operators. Ingle *et al.* (1965) (a study excluded from this review; Table 1), found no significant difference in success rates of treatment carried out by undergraduates or private practitioners, in agreement with Cheung (2002) who reported the qualification and experience of operator had no influence on treatment outcome.

The majority of the reviewed studies classified operator qualification as: undergraduate students (21 studies), GDP (seven studies), postgraduate students (four studies) or specialists (23 studies). In five studies, treatment was carried out by a mixed group of operators and three studies did not provide this information. From the results, treatment carried out by postgraduate students and specialists had the highest weighted pooled estimate of success, regardless of strict or loose criteria (Table 4).

Source of heterogeneity

As the radiographic criteria for success have already been shown to have a significant effect on the pooled success rates, further meta-regression analyses were therefore carried out, separately on success rates based on strict or loose criteria, to explore which of the other study characteristics were potentially responsible for the statistical heterogeneity. None had significant effects on the success rates reported by the studies or could account for the heterogeneity (Table 5) in estimating the pooled success rate of primary root canal treatment.

Table 5 Results of meta-regression analysis to account for the source of heterogeneity

	Strict		Loose	
Covariate included	I^2	τ^2	I^2	τ^2
No. covariate included	0.985	0.0247	0.973	0.0085
Year of publication (before 1970s, 1970–1989, 1990–2002)	0.983	0.0265	0.971	0.0098
Geographical location of study (USA, Scandinavian or other countries)	0.984	0.0244	0.952	0.0069
Unit of measure (root or tooth)	0.984	0.0253	0.961	0.0081
Qualification of operator (specialist, postgraduate, undergraduate, GDP or mixed group)	0.979	0.0209	0.974	0.0073
Criteria for success (radiographic vs. combined radiographic & clinical)	0.986	0.0254	0.974	0.0088
Duration after treatment (at least 4 years or shorter)	0.985	0.0228	0.973	0.0085
Recall rate	0.986	0.0218	0.975	0.0117

GDP, general dental practitioners; I^2, proportion of total variation due to heterogeneity across studies; τ^2, estimate of between-study variance (if the I^2 and τ^2 values were reduced by 10% after including a covariate in the regression model as compared with the values estimated without any covariates entered, the respective covariate was considered to be a potential source of heterogeneity).

Discussion

Most of the selected studies were prospective cohort or retrospective studies, therefore the levels of evidence provided by them are grade B (levels 2 or 3) based on the criteria given by the Oxford centre for evidence-based medicine (Phillips *et al.* 1998 http://www.cebm.net/index.aspx?0=1025). There were only six randomized trials investigating different aspects of root canal treatment procedures on outcomes, including the effects of sealers (AH26 [DeTrey AG, Zurich, Switzerland]; Procosol [Star Dental, Conshohocken, PA, USA], Kloropercha) (Ørstavik *et al.* 1987); root filling materials (Hydron® [Hydron Technologies, Pompano Beach, FL, USA], gutta-percha with AH26® sealer) (Reid *et al.* 1992); single-visit versus multiple-visit root canal treatment (Trope *et al.* 1999, Weiger *et al.* 2000, Peters & Wesselink 2002); use of $Ca(OH)_2$ dressing versus no medicament in multiple-visit treatment (Trope *et al.* 1999); and the use of stainless steel versus nickel–titanium hand files (Pettiette *et al.* 2001).

The Cochrane Oral Health group's current guidelines for a systematic review states that 'the scope of the review is to include all RCTs, where RCTs are inappropriate, rather than unavailable, other levels of evidence may be considered' (http://www.ohg.cochrane.org/forms/writing_review.pdf September 2006). However, the authors decided that the numerous observational studies, whilst not having the feature of randomization or control groups, represented useful and useable data that could not be deemed inferior by any other criteria. Instead of using exclusion rules to control the heterogeneity of design, this systematic review followed the recommendation by Stroup *et al.* (2000). Broad inclusion criteria for studies were used and analyses were performed to investigate the effect of study characteristics on the estimated pooled success rates. Despite using broad inclusion criteria, several well designed and executed studies such as those by Strindberg (1956), Ørstavik and Hörsted-Bindslev (1993); Ørstavik *et al.* (1986) and others (Table 1) had to be excluded.

The goal was to explore the available data and partition it to reveal the effect of study characteristics, general patient factors, individual pre-, intra-, and postoperative factors on treatment outcome, whilst triangulating the outcomes of different approaches of exploration.

Preliminary data collection was carried out by two authors (Y-LN and KG) to explore its diversity. Amongst the studies reviewed, there were substantial variations in study characteristics such as sample selection, definition of successful cases, duration after treatment, type and strategy of data collection as well as data analyses. Some of the potential clinical prognostic factors (tooth type, age grouping, size of apical preparation, definition of apical disturbance, apical extent of root filling, quality of root filling and quality of coronal restoration) were sub-classified differently between studies. Therefore, a strategy for pooling the data by recalculation of the available figures was derived. Based on this strategy, a data collection form was designed, tested, refined and adopted. Despite this, disagreement amongst the reviewers existed ($\kappa = 0.57–0.61$). The disagreement could be traced to a lack of clarity in the presentation of methodology and results. For some studies, data had to be extracted from the discussion section where it was sometimes first introduced. When there was a disagreement, an agreement was negotiated between the examiners by presenting the case for each view. In the majority of cases, the source of errors were easily identified and corrected.

The un-weighted pooled success rate by each factor was calculated based on the approach used by Hepworth & Friedman (1997). However, this approach does not take into consideration, the within and between study variations as opposed to the study–design-specific weighted pooled success rates estimated using random effects meta-analysis. The discrepancies in the success rates estimated using the two approaches are well demonstrated in Table 4. Therefore, the results based on the un-weighted pooled success rates were not considered in the following discussions. The estimation of pooled success rates for some sub-group analyses within some study characteristics were based on small data sets, restricting their value.

The significant difference in success rates judged by strict or loose radiographic criteria has already been iterated but in addition, the data based on strict criteria revealed a clear trend for differences in the pooled success rates from studies adopting different follow-up durations; for example, 6 month follow-up compared with longer duration. It should be mandatory to state the criteria for success as part of the methodology of future clinical root canal treatment outcome studies, preferably stratified by both loose and strict radiographic criteria. The European Society of Endodontology's (2006) suggest a clinical and radiographic follow-up after at least 1 year with annual recall for up to 4 years before a case is judged a failure. The American Association of Endodontists suggests clinical and radiographic evaluation for a 4- to 5-year period, with the additional proviso of determining the functionality of the treated tooth (http://www.aae.org/dentalpro/guidelines.htm). The origin of this is probably based on the work of Strindberg (1956). From a research perspective and based on this review, the cases should be reviewed for a minimum of 1 year and preferably for at least 3 years, after completion of treatment. It would be preferable to standardize the duration after treatment for all the patients or at least to include the duration as a covariate into the statistical model to account for any variations in the success rate because of the different follow-up times. The best choice of statistical analysis would be to analyse time to healing (success) with survival analysis techniques, however, it would require regular follow-up of all patients. The reality is that the longer the duration of follow-up after treatment, the greater the drop-out rate at recall. Therefore, a balance has to be struck between these competing ideals in both the medical and dental fields, although the use of financial incentives may help improve recall rates (Wang *et al.* 2004).

This review also highlighted two important methodological shortcomings in published root canal treatment outcome studies. The variability in radiographic assessment because of subjectivity in radiograph reading is well recognized (Goldman *et al.* 1972), yet the good practice of employing at least two pre-calibrated observers with intra- & inter-observer agreement tests, was not adopted by most of the studies ($n = 56$). In addition, the statistical methods used for analysing the association between potential influencing factors and treatment outcome, did not take account of the effects of potential confounders.

The overall success rates were not affected by 'year of publication' or 'geographic location of study'. In the former category, the measure of relevance should really be the 'year in which treatment was carried out' but few studies provide this information. Nevertheless, the absence of obvious improvement in success rates by the year of publication suggests that the advances in technology and materials used for root canal treatment do not appear to have influenced treatment outcome significantly. Such a suggestion is strongly refuted by endodontists on the grounds that the apparent lack of improvement in success rates is a function of more adventurous case selection fuelled by confidence in better skills and outcomes. The validity of this proposition is explored further in the second part. For the present, it is argued that the lack of improvement in success rates could be attributed to the fact that, whilst technology has improved instruments and materials to achieve a set of goals, the principles underpinning those goals have not changed over the duration covered by this review (Hall 1928). This brings to the fore, the classic debate about the relative value of biological versus the technical principles in dentistry (Noyes 1922, Naidorf 1972). Noyes (1922) lamented that dentists were not trained to think in biological concepts but to act in mechanical procedures; whilst Naidorf (1972) applauding the technical excellence achieved by the pre-occupation of dentists with this element, deplored the lack of biological awareness of the basic pathology of the problem or the biological consequences of the treatment. The clinical academics in this discipline would probably sustain the validity of these assertions, even today. It is interesting to note that the success rates of studies from the North American countries, where the use of contemporary technology is probably most widely recommended fared no better than those from other countries. Furthermore, the adoption of strict radiographic criteria and microbiological awareness in their approach appeared to bring better results in studies performed in the Scandinavian countries. This speculation is important because it centres around the debates that raged in the 1960s and 1970s about the value of the microbial culture test in informing the progress of treatment, a practice, long as abandoned as unnecessary (Engström *et al.* 1964, Mikkelsen & Theilade 1969, Oliet & Sorin 1969, Morse 1971, Sims 1973, Frank *et al.* 1978, Molander *et al.* 1996a,b). This ultimately led to the adoption of single-visit treatment by many endodontists on the basis of the cost-benefit analysis (Spångberg 2001) an issue that will be explored further in the second part. The historical importance of this biological versus technical debate is important to appreciate, because it fundamentally changed the way root canal treatment was conceived and practiced; from a microbially aware post-focal infection era, to one dominated by a technological awareness but relative microbiological ignorance. The problem of geographical location also merits close inspection, as sometimes, a single study may report pooled data from multi-centre evaluations (Friedman *et al.* 1995).

Although the educational and experience background of the operators had no significant influence on their respective success rates in individual studies, the estimated pooled success rates for endodontists or postgraduates were higher than for other dentist groups in this review. The important influence of the background of operators on the technical outcome of endodontic procedures has been demonstrated in laboratory studies (Gulabivala *et al.* 2000, Van Zyl *et al.* 2005) but there is a lack of appropriate tools or methodology to objectively quantify operator skills. The role of such refined technical skills must surely be balanced against the overall understanding of the problem and the motivation and integrity with which the procedure is performed.

Conclusion

The estimated weighted pooled success rates of treatments completed at least 1 year previously, ranged between 68% and 85% when strict criteria were used. The reported success rates have failed to improve over the last four or five decades. The quality of evidence for treatment factors affecting primary root canal treatment outcome is sub-optimal; there was substantial variation in the study–designs. It would be desirable to standardize aspects of study–design, data recording and presentation format of outcome data in the much needed future outcome studies. The second part of this paper will present the results of meta-analyses and meta-regression to investigate the effect of individual clinical factors on the success rates of primary root canal treatment.

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