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REVIEW

Limitations of previously published systematic reviews evaluating the outcome of endodontic treatment

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Abstract

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The aim of this work was to identify the limitations of previously published systematic reviews evaluating the outcome of root canal treatment. Traditionally, periapical radiography has been used to assess the outcome of root canal treatment with the absence of a periapical radiolucency being considered a confirmation of a healthy periapex. However, a high percentage of cases confirmed as healthy by radiographs revealed apical periodontitis on cone beam computed tomography (CBCT) and by histology. In teeth, where reduced size of the existing radiolucency was diagnosed by radiographs and considered to represent periapical healing, enlargement of the lesion was frequently confirmed by CBCT. In clinical studies, two additional factors may have further contributed to the overestimation of successful outcomes after root canal treatment: (i) extractions and re-treatments were rarely recorded as failures; and (ii) the recall rate was often lower than 50%. The periapical index (PAI), frequently used for determination of success, was based on radiographic and histological findings in the periapical region of maxillary incisors. The validity of using PAI for all tooth positions might be questionable, as the thickness of the cortical bone and the position of the root tip in relation with the cortex vary with tooth position. In conclusion, the serious limitations of longitudinal clinical studies restrict the correct interpretation of root canal treatment outcomes. Systematic reviews reporting the success rates of root canal treatment without referring to these limitations may mislead readers. The outcomes of root canal treatment should be re-evaluated in long-term longitudinal studies using CBCT and stricter evaluation criteria.

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

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Introduction

Apical periodontitis may present before and after root canal treatment. Teeth with apical periodontitis may be symptomatic or asymptomatic, functional or not functional. Ørstavik & Pitt Ford (1998), Friedman (2002) and Trope (2003) have defined clinical endodontics as the prevention and/or elimination of apical periodontitis. Accordingly, the aim of root canal treatment is to reduce root infection to a minimal level and achieve absence of post-treatment apical periodontitis (Wu *et al.* 2006).

The outcome of root canal treatment indicates the extent to which the above aims have been achieved. In an effort to provide patients with the most recent, highest quality and most predictable treatment modalities for dental care, clinicians must be well informed

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regarding the outcomes of their proposed treatment. Moreover, the selection of treatment procedures, instruments and materials is often determined based on evidence of a higher success rate. Therefore, evidence-based knowledge of root canal treatment outcomes is a fundamental aspect of endodontics.

Longitudinal clinical studies, including randomized controlled trials, cohort studies and retrospective observational studies provide information about the outcomes of initial root canal treatments and surgical or nonsurgical retreatments (Paik *et al.* 2004, Ng *et al.* 2007). Eleven systematic reviews on the outcome of root canal treatment have been published in the last decade (Table 1), summarizing findings from longitudinal clinical studies published between 1922 and 2006 (Hepworth & Friedman 1997, Peterson & Gutmann 2001, Lewsey *et al.* 2001, Basmadjian-Charles *et al.* 2002, Niederman & Theodosopoulou 2003, Paik *et al.* 2004, Kojima *et al.* 2004, Sathorn *et al.* 2005, Ng *et al.* 2008a, 2008b). Review articles can influence clinicians more than individual clinical studies, because they are considered to represent high-quality (sub-standard) evidence in the absence of sufficient gold standard level data from randomized controlled trials (Ng *et al.* 2007).

However, previously published systematic reviews on the outcome of root canal treatment may have neglected a number of crucial factors affecting the assessment of overall treatment success (Wu *et al.* 2006). One such factor is that periapical radiography was used for all individual clinical studies; this technique has limited value in diagnosing a healthy periapex (Bender & Seltzer 1961, Bender 1982, van der Stelt 1985, Stabholz *et al.* 1994, Huumonen & Ørstavik 2002, Ricucci & Bergenholtz 2003).

The purpose of this work was to highlight the limitations of previously published systematic reviews evaluating the outcomes of root canal treatment.

Periapical radiography

In 57% of clinical studies selected in a review article by Ng *et al.* (2007), both clinical and radiographic findings were used to determine the treatment outcome. As post-treatment apical periodontitis is often asymptomatic, the outcome was determined by radiographic examination alone in the remaining 43% of selected studies. Either strict (complete resolution of existing periapical radiolucency at recall) or loose (reduction in size of existing periapical radiolucency at recall) radiographic criteria were used in these studies.

Although, periapical radiographs have been used to diagnose post-treatment apical periodontitis in all studies since 1922 (Ng *et al.* 2007), the limitations of periapical radiography in diagnosing apical periodontitis were not discussed in any of the systematic reviews listed in Table 1.

The image on radiographs corresponds to a two-dimensional aspect of a three-dimensional structure (Huumonen & Ørstavik 2002). Periapical lesions confined within the cancellous bone may not be detected by periapical radiography. Whilst lesions of a certain size can be detected in regions covered by thin cortex, lesions of the same size cannot be detected in regions

Table 1 Estimated success rate of endodontic treatments reported in previously published systematic reviews (1997–2008)

Author (year)	Country	Treatment	Estimated success (%)
Hepworth & Friedman (1997)	Canada	Retreatment	66
		Apical surgery	59
		Apical surgery with simultaneous retreatment	81
Peterson & Gutmann (2001)	USA	Resurgery	36
Lewsey *et al.* (2001)	UK	Root canal treatment	78
Basmadjian-Charles *et al.* (2002)	France	Root canal treatment	78
Niederman & Theodosopoulou (2003)	USA	Retrograde filling	77
Paik *et al.* (2004)	USA	Retreatment	70
Kojima *et al.* (2004)	Japan	Vital pulp	83
		Nonvital	79
Sathorn *et al.* (2005)	Australia	Single-visit	77
		Multiple-visit	71
Ng *et al.* (2007)	UK	Root canal treatment	75
Ng *et al.* (2008a)	UK	Root canal treatment	–
Ng *et al.* (2008b)	UK	Retreatment	77

covered by thicker cortex, which has been demonstrated in both *in vivo* and *ex vivo* studies (Bender & Seltzer 1961, Bender 1982, van der Stelt 1985, Stabholz *et al.* 1994, Huumonen & Ørstavik 2002, Ricucci & Bergenholtz 2003).

Computed tomography (CT) has been widely used in medicine since the 1970s (Brenner & Hall 2007) and first appeared in endodontic research in 1990 (Tachibana & Matsumoto 1990). Cone-beam technology has existed since the 1980s. Cone beam computed tomography (CBCT) can detect periapical lesions in many cases where no periapical radiolucency can be seen on radiographs (Vandenberghe *et al.* 2008).

Lofthag-Hansen *et al.* (2007) diagnosed periapical lesions in endodontically treated human molar teeth using both periapical radiography and CBCT. Forty-six molars were inspected and 53 lesions were detected by both techniques. In addition, 33 lesions were detected by CBCT only. Jorge *et al.* (2008) infected 76 tooth roots in dogs and detected no periapical lesions with radiographs at day 14 after pulp exposure, whilst 47% of roots showed lesions at day 21. By contrast, CBCT evaluation detected apical periodontitis in 33% of roots at day 14 and 83% at day 21. Cross-sectional studies were considered by some to provide reliable information on the long-term success rate of root canal treatment at a population level (Petersson *et al.* 1991). Estrela *et al.* (2008a) in a cross-sectional study demonstrated post-treatment apical periodontitis in 35% of teeth using periapical radiography and in 63% of teeth using CBCT. This means that in human teeth the success rate determined by CBCT can be approximately 30% lower than that determined by periapical radiography. Paula-Silva *et al.* (2009a) endodontically treated 72 dog tooth roots and the outcome was evaluated at 6 months post-treatment. Unfavourable outcomes (emerged, unchanged or enlarged periapical lesions) were demonstrated in 21% of roots when analysed by periapical radiography, but in 65% when analysed by CBCT. This means that in dog teeth the percentage of favourable outcome determined by CBCT can be 40% lower than that determined by periapical radiography. These findings suggest that complete resolution of existing periapical radiolucency on radiographs does not guarantee a healthy periapex.

Paula-Silva *et al.* (2009b) evaluated the sensitivity, specificity, predictive values and accuracy of periapical radiography and CBCT in diagnosing apical periodontitis, using histopathologic findings as a gold standard. The negative predictive value (NPV) of periapical radiography in diagnosing apical periodontitis was 0.25; thus, 75% of cases confirmed healthy by periapical radiography presented apical periodontitis by histology. The NPV of periapical radiography in diagnosing apical periodontitis was previously reported as 0.53 by Brynolf (1967), 0.55 by Rowe & Binnie (1974), 0.74 by Green *et al.* (1997), 0.20 by Ricucci & Langeland (1998), 0.67 by Barthel *et al.* (2004) and 0.35 by Stavropoulos & Wenzel (2007). The NPV of periapical radiography varied from 0.20 to 0.74 in four studies that analysed human materials (Brynolf 1967, Green *et al.* 1997, Ricucci & Langeland 1998, Barthel *et al.* 2004). The variability of NPV could be explained by different tooth positions of samples selected for different studies. In addition, different radiographic techniques were used (Brynolf 1967, Barthel *et al.* 2004). The NPV of CBCT in diagnosing apical periodontitis was almost twice as high as that of periapical radiography according to Paula-Silva *et al.* (2009b), indicating that CBCT more accurately detected a healthy periapex.

The incidence of periapical healing by scar after nonsurgical root canal treatment is low (Bhaskar 1966, Love & Firth 2009). Love & Firth (2009) performed apical surgery in 100 endodontically treated teeth with persistent periapical radiolucent lesions and found that the incidence of periapical granuloma, cyst, abscess and scar was 77%, 18%, 3% and 2% respectively. CBCT cannot be used to distinguish scar tissue from an inflammatory granuloma, therefore, one may question whether all CBCT detected radiolucencies are true lesions. In a study by Velvart *et al.* (2001), 78 CBCT-scanned human periapical lesions were confirmed to be true lesions during periapical surgery. In a study by Paula-Silva *et al.* (2009b), the positive predictive value was 1 for CBCT in diagnosing apical periodontitis in dogs teeth. This means that when a lesion was diagnosed by CBCT, 100% of the cases were periapically inflamed histologically.

Reduction of the size of radiolucency was considered to represent the healing of the periapical pathology and thus frequently used as radiographic criteria to determine successful treatment (Lewsey *et al.* 2001, Ng *et al.* 2007). Paula-Silva *et al.* (2009a) reported that amongst 30 cases where reduction in size of radiolucency was diagnosed by periapical radiography, 24 (80%) appeared as enlarged lesions in CBCT images. It was found that when lesions expanded in the cancellous bone, frequently in the lingual direction, the enlargement of the lesion could only be revealed by volumetric measurements using CBCT. The diagnosis of reduced periapical radiolucency with radiographs therefore does not guarantee that the healing process has begun or is continuing.

During recent years, progress was made in developing and improving digital radiography; with the new digital high resolution systems the detection of radiolucency may be improved. However, the improved image remains two-dimensional and subject to the limitations of anatomical noise.

Recall rates

The influence of low recall rates on the success rate was not addressed in most of the systematic reviews listed in Table 1.

The recall rate is defined as the percentage of patients that present for follow-up after treatment. Sixty-three clinical studies (1922–2002) were selected in a review by Ng *et al.* (2007), but only thirty-nine studies reported the recall rate. The median recall rate was 52.7%, and the lowest recall rate was 11% (Selden 1974).

According to Friedman (2002), 'When many subjects included in the inception cohort of a study are not available for follow-up, the unknown treatment outcome invalidates the results'. Sathorn *et al.* (2005) only reviewed studies where a high recall rate was reported.

Different terms were used for patients who were followed up after treatment (e.g., 'returnees'), whilst 'dropouts' and 'absentees' were the terms used to denote patients who were not present for follow-up. Ørstavik *et al.* (2004) compared the characteristics of returnees and dropout groups and found that dropout patients had more symptoms and perceived that treatment had failed. Therefore, in studies with large dropout groups, the reported success rate may represent an overestimation.

Efforts have been made to improve the recall rate. In the Toronto studies I, II and III (Friedman *et al.* 2003, Farzaneh *et al.* 2004b, Marquis *et al.* 2006), multiple letters and telephone calls were used to encourage patients to present themselves for follow-up; financial compensation was also offered for travel and loss of work time. In total, 1379 teeth were treated in these three studies; only 374 (27%) were included in the analysis. The outcome of the 73% of treated teeth is unknown; it therefore appears that the measures taken to increase the recall rate were not effective.

Ørstavik *et al.* (2004) suggested a new method to improve the overall recall rate. In that study, the percentage of dropouts increased from 33% at 1 year to 62% at 4 years. Over the 4-year period, 82% of patients were seen at least once, either at 1, 2, 3 or 4 years; only 18% of the patients never returned. Thus, the overall recall rate for the 4-year period reached 82%. However, the year in which the outcome was recorded was not mentioned when patients were seen more than once.

Interestingly, the success rate usually increased over time, in parallel with a decreasing recall rate. The recall rate and success rate for each year during the follow-up period were provided by Ørstavik (1996) and are summarized in Table 2. In total, 155 teeth with preoperative periapical radiolucencies were treated and followed up for 4 years. The recall rate decreased from 71% at 1 year to 33% at 4 years. Meanwhile, the success rate increased from 44% at 1 year to 82% at 4 years. Thus, at 4 years, when only one out of three patients returned, the success rate was 82%. Such an increase in success rate over a 4-year period has been taken as evidence of a gradual periapical healing process (European Society of Endodontology 2006). However, another possible explanation could be that an increasing number of patients with unfavourable outcomes did not return for follow-up.

If this is true, then the 4-year follow-up period (European Society of Endodontology 2006) is unnecessary. Indeed, more than 88% of roots presenting reduced periapical radiolucency at 4 years following treatment had already shown this favourable outcome within 1 year (Ørstavik 1996). Wu & Wesselink (2005) suggested categorizing treatments where the existing radiolucent area was unchanged after 1 year as ineffective and requiring further treatment. Table 2 (Ørstavik 1996) shows that the recall rate at 1 year was more than twice as high as that at 4 years, suggesting that the overall recall rate could have been higher if the outcome had been determined at the end of 1 year. However, the suggestions made by Wu & Wesselink (2005) should be confirmed in studies utilizing CBCT.

Extractions and re-treatments

The systematic reviews listed in Table 1 did not discuss whether extractions and retreatments were included in the failure category.

Table 2 Success rate at 0–4 years post-treatment for 155 teeth with preoperative periapical radiolucency (Ørstavik 1996)

Year	Recall rate (%)	Success (PAI score of 1 or 2) rate (%)
0	100	0
1	71	44
2	60	72
3	55	79
4	33	82

During a period of 4 years or more between treatment and recall (European Society of Endodontology 2006, Ng *et al.* 2007), some teeth were extracted or retreated because of endodontic treatment-related complications (Molander *et al.* 1998, Cheung & Chan 2003). Petersson *et al.* (1991) found that 22% of teeth with failed root canal treatment were extracted. In a systematic review, Hepworth & Friedman (1997) found that 57% of retreatments were performed for 'technical' purposes, whilst 43% of retreatments were performed because of endodontic failures. Cheung & Chan (2003) categorized 314 root canal treated teeth as failures, including 143 (46%) extractions and 55 (18%) surgical or nonsurgical retreatments.

Zadik *et al.* (2008) analysed the reasons for extraction of root filled teeth. Endodontic treatment-related extractions comprised 30% of cases (iatrogenic perforation/stripping 9%, vertical root fracture 9%, endodontic failure 12%). All extractions were considered as failures by Ørstavik *et al.* (2004).

Amongst the 15 studies reviewed by Ng *et al.* (2007) in which the follow-up period was 4 years or longer (Cheung 2002, Chugal *et al.* 2001, Cvek 1992, Cvek *et al.* 1982, Grahnén & Hansen 1961, Halse & Molven 1987, Hoskinson *et al.* 2002, Reid *et al.* 1992, Smith *et al.* 1993, Ørstavik 1996, Sjögren *et al.* 1997, Werts 1975, Peak *et al.* 2001, Ørstavik *et al.* 1987, Sjögren *et al.* 1990), only one included extractions and retreatments in the failure category (Cheung 2002). In the other 14 studies, extractions were either not mentioned or excluded as the reason for extraction was unknown (Hoskinson *et al.* 2002); retreatments were not mentioned at all.

The PAI scoring system

In two reviews (Sathorn *et al.* 2005, Ng *et al.* 2007), the use of the periapical index (PAI) for the determination of success was described. However, the validity of using this index was not discussed in any of the systematic reviews listed in Table 1.

The PAI scoring system suggested by Ørstavik *et al.* (1986) has been used in 58 studies thus far (Table 3). Twenty of these studies were reported between 1987–2003. Thirty-eight were reported between 2004–2008. The number of such publications noticeably increased from one per year between 1987 and 2003, to seven per year between 2004 and 2008. The PAI scoring system seems therefore accepted as a valid tool to determine treatment outcome and to reveal changes in the extent and severity of periapical inflammation after root canal treatment.

Table 3 Fifty-eight studies using periapical index published between 1987 and 2008

Article
Ørstavik *et al.* 1987
Ørstavik *et al.* 2004
Ørstavik 1988
Ørstavik 1991
Ørstavik 1996
Eriksen *et al.* 1988a
Eriksen *et al.* 1988b
Ørstavik & Mjör 1992
Ørstavik & Hörsted-Bindslev 1993
Kerosuo & Ørstavik 1997
Valderhaug *et al.* 1997
Trope *et al.* 1999
Kirkevang *et al.* 2000
Kirkevang *et al.* 2001
Kirkevang *et al.* 2004
Kirkevang *et al.* 2006
Delano *et al.* 2001
Waltimo *et al.* 2001
Waltimo *et al.* 2005
Boucher *et al.* 2002
Dugas *et al.* 2003
Huumonen *et al.* 2003
Friedman *et al.* 2003
Kirkevang & Wenzel 2003
Camps *et al.* 2004
Jiménez-Pinzón *et al.* 2004
Farzaneh *et al.* 2004a
Farzaneh *et al.* 2004b
Peters *et al.* 2004
Segura-Egea *et al.* 2004
Segura-Egea *et al.* 2005
Segura-Egea *et al.* 2008
Wang *et al.* 2004
Yoldas *et al.* 2004
Chazel *et al.* 2005
Marending *et al.* 2005
Quesnell *et al.* 2005
Marquis *et al.* 2006
Peciuliene *et al.* 2006
Ridell *et al.* 2006
Skudutyte-Rysstad & Eriksen 2006
Terças *et al.* 2006
Conner *et al.* 2007
Frisk 2007
Ridao-Sacie *et al.* 2007
Simon *et al.* 2007
Cotton *et al.* 2008
de Chevigny *et al.* 2008a
de Chevigny *et al.* 2008b
Estrela *et al.* 2008a
Estrela *et al.* 2008b
Estrela *et al.* 2008c
Hannahan & Eleazer 2008
Holden *et al.* 2008
Kayahan *et al.* 2008
Penesis *et al.* 2008
Touré *et al.* 2008
Bahrami *et al.* 2008

In the PAI system, periapical radiolucencies are categorized with scores from 1 to 5: score 1 denotes a radiographically healthy periapex; scores 2–5 represent increasing extent and severity of apical periodontitis on radiography (Ørstavik *et al.* 1987). A relative incidence distribution (RIDIT, 0–1.0) is used to indicate the increasing severity of apical periodontitis at the histological level, with 0 representing absence of inflammation and 1.0 representing severe inflammation. According to findings from a histological and radiographical study of the periapical region of human maxillary incisors (Brynolf 1967), the five scores for radiolucency correspond to the five different points of the RIDIT scale. For example, score 2 corresponds to 0.24 in the RIDIT (mild inflammation).

The PAI was based on only one study where the relationship between radiographic and histologic findings was reported (Brynolf 1967). The thickness of the cortical bone and the distance from root tip to cortex varies remarkably for different tooth groups (Huumonen & Ørstavik 2002). The validity of applying the classification based on the maxillary incisor findings of Brynolf (1967) to all tooth groups is thus questionable.

One of the reasons why PAI is gaining popularity could be that PAI allows the reduction in size of an existing lesion to be objectively determined. Ørstavik *et al.* (2004) reported that in 79% of roots, the PAI score decreased from a value of ≥3 preoperatively to a value of 1 or 2 post-treatment. Waltimo *et al.* (2001) reported that the mean RIDIT value decreased from 0.51 to 0.31 after treatment. However, the images on radiographs are two-dimensional, preventing the detection of bucco-lingual lesion expansion. Agbaje *et al.* (2007) and Paula-Silva *et al.* (2009a) used CBCT to measure the extraction sockets or periapical lesions; the volume was recorded in cubic millimetres. This represents a more reliable method for diagnosing reduced lesion size. Lesions frequently expanded in the cancellous bone and in lingual direction, such lesion enlargement was only revealed by volumetric measurements using CBCT (Paula-Silva *et al.* 2009a).

The rationale of including samples exhibiting a PAI score of 2 (corresponding to RIDIT 0.24) in the success category (Trope *et al.* 1999, Friedman *et al.* 2003, Farzaneh *et al.* 2004b, Ørstavik *et al.* 2004, Marquis *et al.* 2006) was probably the prevention of over-diagnosis of disease. However, considering that up to 53% of teeth had a score of 2 at the end of the study (Ørstavik *et al.* 2004), it is likely that many cases with small post-treatment lesions were included in the success category (Ørstavik *et al.* 1987). Ørstavik *et al.* (2004) treated 192 roots with preoperative apical periodontitis. When PAI scores of 1 and 2 were considered to represent successful outcomes, the success rate was 79%; when only teeth exhibiting a PAI score of 1 were considered to represent successful outcomes, the success rate dropped to 26%.

Influencing factors

A number of factors that can influence treatment outcome were discussed in review articles; these factors included the presence of preoperative periapical radiolucency (Basmadjian-Charles *et al.* 2002, Ng *et al.* 2008a), root fillings with or without voids (Ng *et al.* 2008a), root fillings extending to 0–2 mm from the radiographic apex (Basmadjian-Charles *et al.* 2002, Kojima *et al.* 2004, Ng *et al.* 2008a), and the presence of satisfactory coronal restoration (Ng *et al.* 2008a). However, considering that the success rates reported in longitudinal studies might be overestimated, risk factor analysis should be performed again using CBCT to evaluate the data from new studies.

Concluding remarks

Several factors could have contributed to the overestimation of successful outcomes after root canal treatment:

1. A high percentage of cases that are confirmed healthy by periapical radiography present apical periodontitis in CBCT images and histology.

2. In teeth, where reduced size of the existing radiolucency is diagnosed by periapical radiography and considered to represent periapical healing, enlargement of the lesion may frequently be confirmed by CBCT.

3. PAI score 2 (mild inflammation) has usually been included in the success category.

4. Extractions and re-treatments were rarely recorded as failures.

5. The recall rate was often lower than 50% in longitudinal clinical studies.

Previously periapical radiography was the only imaging method available to diagnose post-treatment apical periodontitis. With the development of CBCT techniques, better understanding of the outcome of root canal treatment becomes possible. The outcomes of root canal treatment should be re-evaluated in long-term longitudinal studies using CBCT and stricter criteria. Systematic reviews repeatedly reporting overestimated success rates, as determined by periapical radiography without considering the above mentioned limitations, mislead readers and could eventually damage the reputation of root canal treatment.

Important challenges remain: first, a consensus should be reached that the success rate reported in systematic reviews is likely to be an overestimation. However, longitudinal studies have shown that the periapical radiographs-determined success has a high prognostic validity (Fristad *et al.* 2004, Mead *et al.* 2005), which suggested that success may not require complete and utter radiographic resolution. A discussion on whether all asymptomatic post-treatment apical periodontitis should be treated and the replacement of periapical radiography with CBCT in clinics should follow. A more comprehensive understanding of the true effectiveness of current procedures will stimulate the development of new ideas and strategies, and thus improve the outcome and predictability of apical periodontitis treatment.

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