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Pulpectomy – studies on outcome

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This review is about treatment measures, which may impact outcome of the pulpectomy procedure in endodontic therapy. Clinical trials, conducted over the years, formed the basis for the analysis. While hardly any of the studies reviewed satisfied modern high demands on a controlled desing, reports infer that pulpectomy may be carried out at a very high success provided wound infection is prevented. Under this proviso the management and the level of the apical wound as well as the number of appointments to complete the treatment do not seem to play decisive roles. No scientific basis exists in the literature to support the notion that apical foramen should be pierced and root canals be overfilled for a successful outcome.

Endodontics involves curative measures to treat teeth with injured or diseased dental pulps, whether they are directly exposed to the oral environment, inflamed or necrotic. While the immediate purpose is often to attain relief of a painful condition, the long-term objective is to exclude the root canal system as a source of infection. Thereby threats of recurring painful symptoms and adverse, both local and systemic, effects are likely to be prevented. Per definition, pulpectomy is the procedure carried out in endodontics to remove the bleeding vital pulp although often inflamed in a tooth and replace it with a root filling. The treatment is primarily prophylactic in that it aims to prevent the development of an infected pulp necrosis and associated inflammatory sequels in the periapical tissue compartment. Penetrating caries is a common reason for carrying out this procedure. Pulpectomy is also considered the treatment of choice for the management of severe painful lesions emanating, for example, from caries or previous dental treatment procedure.

The critical steps to accomplish the objectives of endodontic therapies have been outlined in clinical practice and tested over many years of research. Hence, numerous clinical follow-up studies have indicated that predictably good results, from an infection point of view, can be obtained with proper mechanical instrumentation, disinfection and complete filling of the instrumented root canal(s) with a biocompatible material that does not dissolve over the course of time (e.g. (1–3), see also review by Spångberg (4)). Yet many issues related to the various elements in the performance of endodontic treatments are still controversial and heavily debated (5). As far as the pulpectomy procedure is concerned, the location and the management of the apical wound and the number of appointments required to complete the treatment, in particular, have attracted divergent opinions over the years. One aim of this review was, therefore, to examine existing documentation on these issues. The review also evaluates the clinical studies, so far conducted, which have assessed the success rate of the pulpectomy procedure.

This paper is an adaptation of the literature review in Dr Gesi's thesis for Licentiate Degree in Odontology at the Faculty of Odontology, Sahlgrenska Academy, Göteborg University, Sweden. The thesis 'Incidence of Postoperative Pain and Osteolytic Lesion after Pulpectomy' was defended on November 14, 2003.

Historical perspectives

Prior to the invention of local anesthetics, options to remedy pulpal injuries and associated painful conditions were highly limited. Over many years, extraction of the tooth in question represented the only realistic solution, thereby eliminating not only the immediate cause of the pain condition, but also the risk of subsequent pulp tissue breakdown and development of periapical abscesses.

Over the years, a variety of endodontic procedures, aimed to permit maintenance of the tooth without a compromised inflammatory state, have been advanced. They include techniques to preserve the pulp or parts thereof by pulp capping and amputations at various levels to complete removal of the tissue (pulpectomy, pulp extirpation). One distinct limitation of any of these techniques before more modern times was the lack of ways to conduct the operations painlessly. The principle of devitalizing the pulp with tissue toxic chemicals such as arsenic and paraformaldehyde was, however, an important invention at the time and made it possible to operate on the tissue and even remove it without much pain. This method, termed mortal pulpectomy, was a forerunner of the current (vital) pulpectomy procedure.

In 1879, Witzel (cited by Lambjerg-Hansen (6)) suggested the much less invasive and time-consuming mortal pulpotomy method. The basic principle of this treatment was to leave out the instrumentation procedure and retain the devitalized pulp tissue in the canal. The tissue was usually amputated at the entrance of the root canal(s), which was subsequently sealed with strong antiseptic cement, the idea being to keep the fixed tissue permanently disinfected. In 1899, Gysi (7) advocated tricresol, creolin and trioxymethylene for this procedure. This agent was termed Gysi's trio paste.

In the western world, during the first half of the last century, mortal pulpotomy gained substantial popularity. For pulp devitalization, paraformaldehyde treatment was the state-of-the-art technique for decades. It became a common procedure to submit the pulp of the more curved and narrow buccal and mesial canals of upper and lower molars, respectively, to this procedure, while it was being extirpated and replaced with a filling in the straighter canals.

While mortal treatment of diseased yet vital dental pulps remained in vogue for quite a number of years and even gained support in clinical follow-up studies (see review by Lambjerg-Hansen (6)) concerns were raised as to its biological incompatibility. Davis (8) was early to express the opinion that pulp operations should be performed with nerve blocks and not by arsenic. Clearly the devitalization procedure and the strong antiseptics subsequently used entailed severe tissue toxic effects. The potential risk for leakage of the devitalizing agent to the gingival sulcus along the provisional filling was especially discouraging. Such a complication could generate bone tissue necrosis, sequestration and a permanent periodontal defect. The fading bactericidal properties of the mummifying agent over time became another concern when late failures of the treatment began to emerge (9).

While still practiced in some Asian and European countries (10, 11), neither mortal pulpotomy nor mortal pulpectomy are no longer considered appropriate. However, clinical follow-up studies showed that the success rate of mortal pulpectomy as judged by clinical and radiographic criteria could be as high or even higher than that of vital pulpectomy ((1, 2, 12, 13), see also review by Lambjerg-Hansen (6)). Interestingly, Eriksen et al. (11) noted in a survey of reports on prevalences of apical periodontitis that success rates of endodontic treatment in two European countries, where toxic formaldehyde-containing dressings are widely used, were higher than that in countries where biocompatible approaches to endodontic therapy are advocated.

The current approach to invasive pulpal therapy by removing the vital pulp by mechanical means became a more widespread procedure when improved agents for local anesthesia were introduced in the 1920s. The lack of understanding of the need to maintain aseptic techniques during the procedure and careless consideration of the fact that apical foramina rarely exit at the root apex, led to numerous failures. In a series of forthright papers, Davis (8, 14) noted this and strongly advocated an aseptic operative procedure including the use of sterilized instruments and of chemically disinfected rubber dams. Davis (14) also called attention to the studies of the anatomy of the root canal system carried out by Hess (15) and made the point that it would be impossible to predictably remove the entire soft tissue in these apical ramifications of the canal. Therefore, he suggested that the pulp be cut at some distance from the anatomical apex, and termed this procedure partial pulpectomy (16) as opposed to total pulpectomy or pulp extirpation, which implies removal of the entire tissue down to the apical terminus.

Groove (17) observed in histological sections of treated cases that following instrumentation, an apical obliteration of the root canal with the development of 'secondary cementum' could occur, indicating the development of an apical block induced by biological means. He considered this 'making a perfect root filling following pulp removal'. Davis (16) made similar observations, which further motivated to the view that at least a small part of the pulp should be left after

instrumentation so that, at each of the foramina, a hard-tissue closure of the root canal at the apex could be attained.

However, it took years before this mode of treatment gained more universal acceptance. The notion remained that especially when the pulp was deemed to be in a state of irreversible inflammation as suggested by lingering pain after provocation with various externally derived stimuli, the entire tissue should be extirpated and the root canals be filled to the apical terminus. Such views are still held (18).

Wound healing studies

Critical to the prevalent view that keeping a short safety distance to the anatomical apex in conjunction with pulpectomy is beneficial to a successful outcome are the numerous histological studies carried out in humans and laboratory animals. Both Strömberg (19) and Lambjerg-Hansen (6) have given comprehensive reviews of many of the early reports. Here shall only some more recent key observations be conveyed. While the first histological studies on human beings were based on small and largely undefined clinical samples, the experimental studies in the thesis of Nygaard-Østby in 1939 (20) gained substantial attention. The material was based on 20 extracted teeth treated with either partial pulpectomy or total pulpectomy. Observation periods were from 1 month to several years. Histological examinations, carried out on block sections, including the root tip with the surrounding bone tissue, indicated partial pulpectomy to be the preferred operation. In a later series of experimental investigations in dogs and human beings, he observed that soft- and hard-tissue repair would take place even if the canal was filled substantially short after overinstrumentation and became filled with blood from provocation of the periapical tissue (21). In some cases, fibrous tissue reached very far into the instrumented pulp chamber. In a subsequent paper (22), these findings were confirmed, while in a report by Nygaard-Østby & Hjortdal (23) similar healing failed to take place in cases of pulpal necrosis. These findings point to a significant repair and regenerating capacity of the apical periodontal tissue as well as an ability to refill any space left after an instrumentation procedure. The important proviso for these results was clearly that the tissue remained non-infected.

A parallel to these findings by Nygaard-Østby and collaborators (20–23) is the study by Hitchcock et al. (24). They investigated the potential of tissue healing in pulps of monkeys following vital root transection carried out with a bur in the mid-portion of teeth. The tissue healing was followed sequentially over a 1-year postoperative period. Initially, there was destruction of the normal pulpal architecture (pulpal necrosis) in the coronal fragment with subsequent early replacement of this tissue by periodontal ligament tissue. The ingrowth of fibrous elements continued over time along with a cellular cementum lining of the root canal after some initial hard-tissue resorption in all specimens. By the stop period, the periodontal ligament-like tissue occupied the entire pulpal chamber. It should be noted that the regeneration of tissue in the set of experiments carried out in these studies occurred in the absence of an interfering root filling material and was most likely facilitated by the relatively large opening of the root canals to the periodontal tissue environment.

It needs to be pointed out that these experiments are not described with the purpose to advocate an altered pulpectomy procedure. However, they should be considered in the debate on whether or not there is a need to attempt removing the entire pulpal tissue to the apical terminus. The experiments referred to clearly demonstrate the opposite namely that, in the absence of infection, regeneration and repair will take place regardless of whether the wound level is placed near or at some distance to the anatomic apex.

To examine the effect on the remaining pulp of certain medicaments and root filling materials, Engström & Spångberg (25) used clinically healthy human premolar teeth in young individuals to be scheduled for extraction as part of an orthodontic treatment. The study comprised 12 contralateral pairs of teeth. They observed the tissue response to filling the pulpectomized root canals with calcium hydroxide or fillings with conventional gutta-percha sealed with chloropercha. The operation was conducted with blunted Hedström files for cutting the apical tissue smooth and relatively close to the apex. One tooth, chosen at random, was filled with calcium hydroxide paste, while the contralateral tooth received conventional root canal filling after a dressing with 2% iodine in potassium iodide for 3–5 days. There was a careful check of the bacteriological status prior to filling and no bacterial organisms were recovered from any of the specimens. The result after the calcium hydroxide filling was clearly superior and revealed

hard-tissue repair at the calcium hydroxide tissue interface with absence of inflammatory cells in the residual pulp tissue. Where lateral canals were in contact with the dressing, hard-tissue repair may have sealed off the orifice. The conventional root fillings, on the other hand, were often associated with inflammatory cell infiltrates and an absence of hard-tissue closure, suggesting a tissue toxic effect similar to the findings of many other reports ((26, 27), see also reviews by Ricucci (28) and Schmalz (29)). Again these findings demonstrate that, in the absence of infection, tissue healing may take place within the confines of the root and, more favorably so, if there is a block against interferences of a tissue irritating root filling material (30).

Rationales for an interappointment dressing with calcium hydroxide

In invasive endodontic treatment of teeth with vital pulps by pulpectomy, the root canal space may become infected (31, 32), while, prior to the treatment, the tissue especially in its apical portion is normally non-infected. The infection may emanate from any breach of the aseptic chain of procedures undertaken during the operation, including improper rubber dam isolation. Bacterial organisms may also derive from micro-abscesses and carious dentinal shavings in the coronal pulpal tissue, which may be brought to the apical portion of the root canal by the instrumentation procedure. The bacterial exposure, thus inadvertently induced, is likely to become a critical factor, especially upon incomplete removal of the pulp tissue, which may follow even the most careful instrumentation (33). Therefore, measures to enhance bacterial killing and removal of pulp tissue remnants from the canal walls are crucial (34, 35). Liquid disinfectants were commonly used in the past but have been replaced in recent years by pastes or slurries of calcium hydroxide, which have gained considerable popularity in recent years (for reviews see (36, 37)).

B. W. Hermann is considered to have introduced calcium hydroxide to endodontics, although many before him used this substance in endodontic therapies (see review by Staehle (38)). Hermann's interest in this agent emerged in the context of the search, at the time, for effective antimicrobials for treatment of teeth with non-vital pulps. The probable reason for selecting this agent as an intracanal dressing was its high pH (pH > 12 in a water slurry).

Calcium hydroxide is a white odorless powder with the formula $Ca(OH)_2$. It is chemically classified as strongly basic and has a molecular weight of 74. It is poorly soluble in water (0.16 g/110 g water at 20°C) and it is insoluble in alcohol. The low solubility, in turn, is clinically useful as the material can be retained in root canals for quite a long period of time before tissue fluids dissolve it. On suppurative apical lesions and in cases of wide-open root apices, that process may proceed fast and necessitate rapid change of the medication (39). The main biological action of calcium hydroxide comes from the ionic dissociation of Ca^{2+} and OH^- ions, where the latter have a distinctly caustic effect that leads to tissue destruction as well as death of bacterial organisms (40). When exposed to carbon dioxide (CO_2) or carbonate ions (CO_3^-) in biological tissue, the dissociation of the chemical leads to formation of calcium carbonate and an overall consumption of Ca^{2+} ions (38). While approaching a neutral pH, which consequently results in less biological and antibacterial activity, the material becomes even less soluble. The transformation over from calcium hydroxide to calcium carbonate at tissue interfaces is a probable explanation of its quite limited tissue destructive effect under *in vivo* conditions.

One common use of calcium hydroxide has been for wound dressing in pulp capping and pulpotomy procedures. The effects of calcium hydroxide on superficial pulpal wounds have been well studied and described (41–43), reviewed by Schröder (44). It causes a superficial coagulation necrosis adjacent to which a mineralizing matrix is formed by repairing cells in both the coronal pulp (45–46) and in the apical portion of the tissue (25). However, a medication with calcium hydroxide is not the only means by which closure of the root canal space at the apical portion and at lateral canals can be achieved. It has long been known that non-infected dentin chips have a similar capacity (47) and may generate similar favorable conditions conducive to tissue healing subsequent to pulpectomy (3, 30).

One vs. two treatment sessions

The use of an intermediate calcium hydroxide dressing to enhance wound healing necessitates at least two treatment sessions. The need for such a measure especially following pulpectomy has been put to question. Given the fact that even following a carious

exposure the infectious process does not reach far into the pulpal space (41, 48–50), a one-step treatment seems reasonable since the procedure is basically surgical and does not demand as strong an emphasis on canal disinfection as is the case with infected pulp necrosis (for review see (36)). The one-step treatment certainly presents several advantages (51). The total time for treatment is reduced and it saves the patient both travel time and expenses. From a treatment point of view, a one-appointment treatment also offers the advantage that curvatures, irregularities and other aberrations in the canal anatomy as well as working-length determinations are current to the operator, thus facilitating the filling procedure that is likely to be easier than at a later appointment. Studies have also indicated that the occurrence of postoperative pain may not be more prevalent in teeth permanently filled in one-step treatments than in two or multiple visits (e.g. (52, 30, 53), see further below).

A two- or multiple-step treatment, on the other hand, permits observation of prevailing clinical symptoms be subsided prior to the final fill of the instrumented root canal(s). Two-step and multiple appointments have also been seen as necessary to optimize cleaning and disinfection. In this context, calcium hydroxide has long been considered the ideal interappointment medication (see reviews by Staehle (38) and Siqueira and Lopes (37)). Based on its high pH in a water slurry, it serves as a disinfectant as well as tissue remnants, inadvertently left on the canal walls in conjunction with the procedure, are necrotized and more efficiently dissolved by NaOCl irrigation at a second appointment (35, 54, 55). Wakabayashi et al. (56) studied the effect of calcium hydroxide paste dressing on uninstrumented root canal walls and found that the odontoblastic cell layer was dissolved after 1 week of dressing and that the debris was removed with 10 min of ultrasonic irrigation. However, neither the predentine layer nor the odontoblastic processes in the dentinal tubules were affected. They remained intact after 1 week of dressing. Four-week dressings were necessary to help wear off the predentine surface and remove the odontoblastic processes from the tubular openings.

It seems reasonable to assume that a measure that enhances canal cleanliness and thereby not only eliminates substrate for bacterial growth, but also provides conditions for an optimal root canal filling that can resist risks of coronal leakage (57) would be beneficial. A further perceived advantage of $Ca(OH)_2$ medication, as reviewed above, is that it may stimulate hard-tissue repair at soft-tissue interfaces in the apical region and at lateral canal orifices or both, thereby causing a biological block to extrusion of root filling material (25). Yet, like many of the procedures and treatment measures recognized as significant to the outcome of endodontic therapy, there is little hard evidence in terms of randomized, prospective clinical trials that support the use of intermediate dressing with calcium hydroxide following a pulpectomy procedure.

Clinical outcome studies

A large number of clinical follow-up studies conducted over more than 50 years (58) has assessed the outcome of the pulpectomy procedure (Table 1). Data on treated cases have been recorded, grouped and analyzed, and conclusions have been carried over to clinical practice. Although there is substantial variation in the design between studies (see below), many have found that the success rate of pulpectomy, when carried out properly (Fig. 1) can be very high, that is in the 90% range. Less successful results have been found in epidemiological surveys (for review see (11)) and in studies where due attention to aseptic operating principles have not been adhered to (59), highlighting the importance of taking careful measures to prevent bacterial contamination of the canal space during the procedure. Such a view is supported by findings of a higher success rate in cases with a negative bacterial culture prior to the final fill (60). Strindberg (1) observed in his thesis that significantly fewer lesions were present at follow-up when the filling was adequate rather than shrunken, when it was confined to the root structure as opposed to flush and overfill and when the size of the apical foramen had been retained rather than overinstrumented. These findings implicate both coronal leakage (57) and apical leakage of bacteria as well as the apical extension of instrumentation and filling as significant to the outcome.

As to the outcome in one or two appointments, Oliet (53) made comparisons in a set of cases he had treated in his own practice. At a minimum of 18 months of follow-up, he observed, among 146 teeth with a vital pulp condition, a similar success rate of 89% and 84% for the one- and two-step procedures, respectively. In another study, often cited, Pekruhn (61) reported a very high success rate in a large sample of teeth

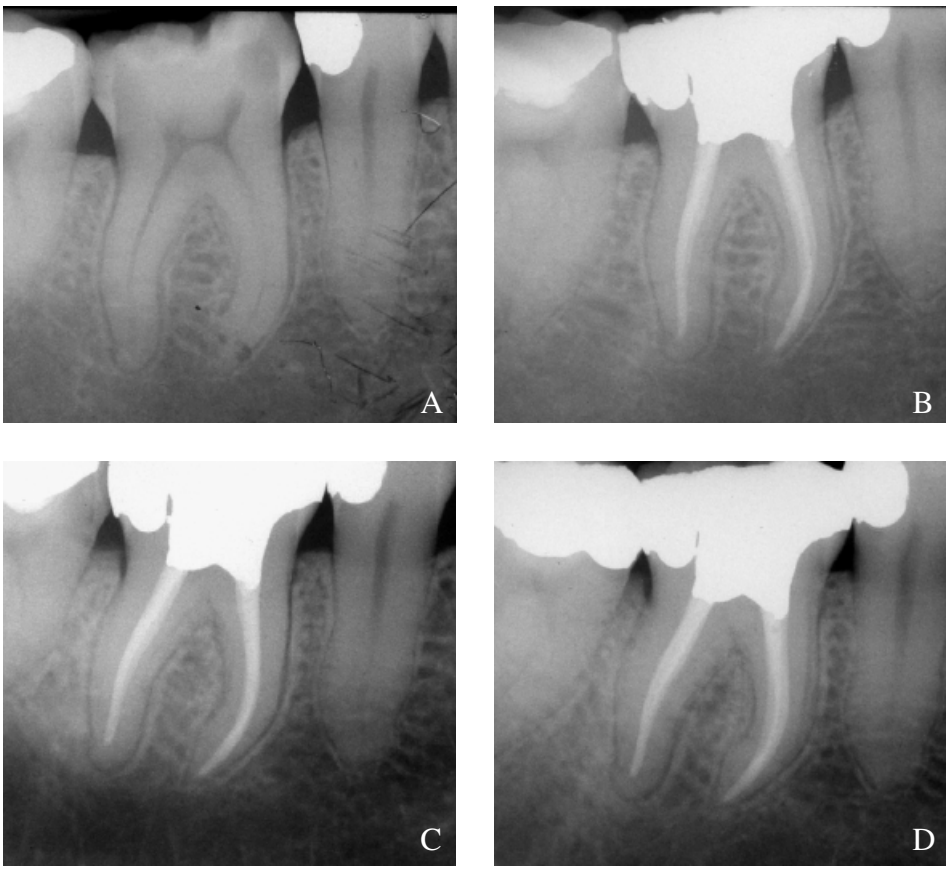

Fig. 1. Pulpectomy of tooth #46 following a carious exposure of the pulp. (A) Preoperative radiograph. (B) Immediate postoperative control demonstrating adequate length and density of filling. (C and D) Two- and 3-year postoperative control radiographs, respectively, show normal peripapical bone structures.

including 604 pulpectomies. These cases, instrumented and filled in one sitting, were reported to be 98% successful. It should be remarked that both these reports are retrospective in nature. The Oliet (53) study made no selection of test and control teeth based on a randomization procedure. Furthermore, in both studies a biased evaluation was carried out in that the assessment of clinical findings and radiographs were performed without the examiner being blinded as to the treatment procedure.

Petersson et al. (30) gave detailed and proper accounts on the performance of a follow-up study on pulpectomies carried out by two endodontists. The purpose of that study was to observe the outcome after creating a dentin chip plug in the apical portion of the root canal prior to either completion of filling in one sitting or following filling the instrumented canal with a calcium hydroxide dressing in between two treatment sessions. Regardless of the number of appointments an equally high success rate of 92% of the roots examined was attained.

Painful symptoms after single-appointment pulpectomy

Single-appointment therapy does not appear to render treated teeth inherently more painful than multiple-visit therapy (69–72) (Table 2). In the studies referred to, it should be noted that no clear distinction was made between teeth with vital and non-vital pulps. Hence, as far as pulpectomy is concerned, there is no clear picture as to the risk involved of developing more painful teeth after one or the other mode of treatment. Furthermore, in some of these studies, the time of observation has not been clearly stated (69, 72). O'Keefe (69) concluded from his results that 'there was no significant differences in the total postoperative pain responses after one-visit or two-visit endodontic therapy'. By contrast, Soltanoff (70) reported slightly more postoperative pain in the one-appointment treatments as compared with the multiappointment procedures. In that study, there was no difference in healing rate upon recall.

Table 1. Success rates reported in various clinical follow-up studies on pulpectomy in which it is possible to distinguish vital from non-vital pulp therapies

	Operator	Follow-up period (years)	Number of cases	Percent available for recall	Success (%)
Strindberg (1)	D	4	187 (roots)	74%†	80
Grahnén & Hansson (2)	S	4–5	570 (roots)	64%	85*
Engström & Lundberg (31)	S	3.5–4	173	73%	78
Heling & Tamshe (62)	S	1–5	63	27%†	78
Adenubi & Rule (63)	D	1–7	267	93%	93
Jokinen et al. (59)	S	2–7	441	46%†	54*
Ashkenaz (64)	D	1–2	145		97
Kerekes & Tronstad (3)	S	3–5	260 (roots)	78%	92*
Pettersson et al. (30)	D	3–6.5	156 (roots)	82%	92*
Oliet (53)	D	>1.5	146		84–89
Sjögren et al. (65)	S	8–10	267	46%†	96
Smith et al. (66)	D	>5	216	54%†	90
Friedman et al. (67)	D	0.5–1.5	108	78%†	93
Ørstavik (68)	D	1–4	473	82%†	94

D, dentists; S, students.
*Uncertain results are included in the unsuccessful therapy.
†Percentage figure refers to the total number of teeth treated in the study including non-vital pulp treatments and re-treatment cases.

Variables affecting outcome of treatment in clinical trials

Available knowledge on the extent to which a given measure in terms of medication or mode of instrumentation leads to a successful outcome following pulpectomy is not only hampered by lack of randomized clinical trials, but also the reports listed in Table 1 vary in terms of the patient material, treatment procedures employed, as well as of method and criteria for analysis of the results. Some of the research included only single-rooted teeth, whereas other studies refer to all types of teeth. Inclusion of multirooted teeth is likely to affect the trial outcome in that operative complications such as ledges, transportations and incomplete pulp tissue removals are normally more prevalent in these teeth and, therefore, could have a negative impact on the results. Yet, surprisingly, some studies have found a higher success rate in molars than in incisors, especially the upper lateral (1–3, 73, 30), suggesting involvement of other confounding factors than just tooth type. Published case series have also made use of either tooth or roots as unit of observation, thus neglecting the effect of variation between individual patients. In addition to these factors, there are a number of other variables in clinical studies that may influence outcome. These include type and quality of postoperative coronal restoration and variation in patients lost to follow-up. If large, the latter variable may constitute another major source of bias as the factors to which such losses are related are usually largely unknown and may have given different results than if these patients had been included.

Length of observation period

The length of the observation period subsequent to the completion of an endodontic treatment procedure is important for valid conclusions. Certainly, time must be

Table 2. Incidence of postoperative pain in various studies following pulpectomy and root filling in one, two or multiple appointments

			One visit			Two or multiple		
Author	Teeth	Pulp conditions	Cases	No pain or mild	Moderate or intense	Cases	No pain or mild	Moderate or intense
Fox (52)	A–P	V–N	204	204 (100%)	0	Not studied		
O'Keefe (69)	A– P	V–N	55	54 (98%)	1 (2%)	77	70 (91%)	7 (9%)
Soltanoff (70)	A –P	V–N	88	71 (81%)	17 (19%)	193	166 (86%)	27 (14%)
Ashkenaz (64)	Mono-rooted	V	195	187 (96%)	8 (4%)	Not studied		
Rudner & Oliet (71)	A–P	V–N	98	87 (88%)	11 (11,5%)	185	164 (88%)	21 (11%)
Oliet (53)	A–P	V–N	264	264 (100%)	0	123	123 (100%)	0
Roane (72)	A–P	V–N	250	212 (85%)	38 (15%)	109	75 (69%)	34 (31%)

A, anterior teeth; P, posterior teeth; V, vital pulp; V–N, material based on both vital and non-vital pulps.

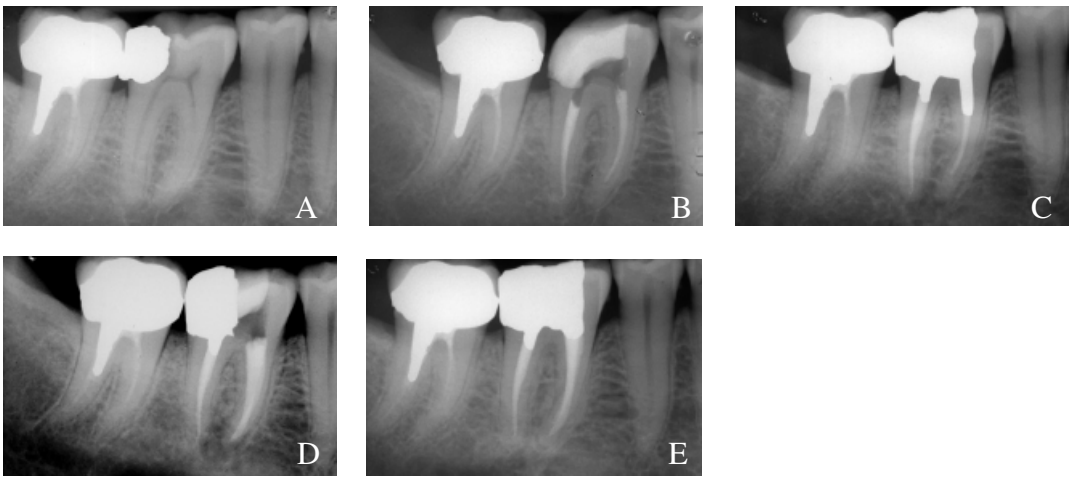

Fig. 2. Pulpectomy of tooth #46 because of secondary caries into the pulp. (A) Preoperative radiograph. (B) Immediate postoperative control. (C) One-year follow-up. Patient presents with a symptomatic tooth (pain and percussion sensitivity). Radiograph shows an osteolytic lesion associated with the mesial root. (D) Postretreatment radiograph. (E) Two-year postoperative control. Tooth is comfortable and shows normal peripapical bone structures.

allowed for healing after the surgical trauma. Time is also required to observe whether or not a wound infection has emerged. While in the absence of infection, resolution to the surgical trauma should not take more than a couple of weeks, the development of a lesion due to infection may require months or even years to become diagnosable (Fig. 2). The chemical irritation (74) and foreign body reaction (75) initiated by the root filling material may also cause periapical bone lesions that may take time to resolve (76, 27). Consequently, the treatment outcome observed after a short time period may differ from that observed at later time periods. In fact, Engström & Lundberg (31) in their follow-up of partial pulpectomies in student cases observed a significantly higher rate of failures at the 3.5–4-year follow-up than at the 1-year check, confirming the findings of Strindberg (1). Several studies in Table 1 included cases observed for only 6 months. Such short observation periods may not reflect the long-term outcome of the therapy, although the probability of the emergence of a lesion beyond the 1-year follow-up is not likely to be high (68). Ørstavik (68) recorded that the peak incidence of emerging apical periodontitis was at 1 year. Assessments carried out after 2, 3, and 4

years of follow-up did not show an added risk for development of apical periodontitis. The rate of recall in the Ørstavik study for the 3- and 4-year follow-ups was, however, relatively low. Thus, some late occurring failures may have escaped detection in that study.

Another consideration in endodontic follow-up studies relates to the risk of coronal leakage from caries or along restorations and root fillings with marginal gaps (57). Thus, lack of proper caries control or improper restoration may be the cause of late occurring failures. However, on the basis of the reports of Ricucci et al. (77) and Ricucci & Bergenholtz (78), coronal leakage may not be such a significant factor for lesion development, if the endodontic treatment is well conducted. In these studies, well instrumented and filled root canals had either lost their restoration and/or caries had penetrated to the vicinity of the root filling. Yet few of the cases showed osteolytic lesions at the follow-up checks and in hardly any were organisms identified by staining in histological tissue sections within the apical portions of the treated root canals.

Loss of patients to follow-up

Loss of substantial numbers of patients to follow-up hampers the validity of clinical trials. On reviewing the literature, many studies suffer from very low recall rates (62, 59, 66). Other studies, although reporting on a reasonably high percentage of patients originally treated (63), have followed a retrospective study design, and the recalls were often assembled over a gap of time of several years with different follow-ups for individual cases. Adenubi & Rule (63) had a 93% recall over a period of 1–7 years, and Jokinen et al. (59) 46% over 2–7 years. Sjögren et al. (65) recall rate was only 46% but over a credible period of 8–10 years.

Analysis of radiographs

Whether a given endodontic procedure such as a certain mode of pulpectomy is considered appropriate, depends on the extent to which it results in apical healing. Ability of examiners to identify the presence or absence of bony lesions in radiographs, subsequent to treatment, is therefore a key element. It is well known that for a lesion to be visible, there has to be sufficient loss of mineral to allow the eye to detect differences in radiographic density. Indeed studies have shown that bone lesions encompassing cortical bone are easier to identify than those limited to the cancellous bone, which may often escape detection (79). In recent years, a number of techniques have been developed which facilitate lesion detection in comparison with conventional radiography including multimodal narrow-beam systems and micro-computed tomography. Subtracted digital radiography is yet another invention in this context that has shown a great deal of promise and which may result in improved inter- and intraexaminer agreement (80). In clinical follow-up studies in endodontics, the value of these techniques have yet to be assessed.

Conventional radiography requires carefully taken and processed radiographs. To provide proper conditions for interpretation, it is mandatory that they depict the whole root complex, the periodontal ligament space, the apical lamina dura, and a substantial portion of surrounding bone in appropriate angulations. Even so, the well-known problem of observer variation and bias is not eliminated and exerts a great influence on reported rates of success or failure of a given endodontic procedure (81–83). Over the years, a variety of strategies have been attempted to improve the evaluation of the periapical tissue status. Yet none can as yet be said to be the most accurate. In a review of methodologies, Halse et al. (84) concluded, as to the evaluation of the problematic borderline cases, i.e. cases with minor inflammatory apical processes that may be classified in a normal or lesion category, that joint discussion between examiners could be beneficial. Such an analysis should take the periodontal ligament space, the lamina dura and the trabecular bone pattern into consideration.

Concluding remarks

The choice of treatment methodologies in endodontics has various implications and should be based on aspects that relate both to the clinical feasibility of the method and its biological effects. Some endodontic methodologies, although biologically compatible, may be time consuming and difficult to master to the extent that they simply cannot be considered justified. Others may allow a rapid operation but the result may not always be predictable or safe enough for the patient to make routine use defensible. Therefore, properly designed clinical trials examining factors that are likely to affect the outcome of endodontic therapies are highly called for (85). Unfortunately, few studies exist which satisfy modern high demands on an unbiased evaluation, set observation times and a randomized sampling where a presumed, unique factor of significance to outcome has

been isolated and tested while other determinants are held constant. With few exceptions, current knowledge is based on retrospective case series, which have involved many operators, where both treatment and outcome evaluations have lacked stringent protocols and where event time has not been identified or calculated as a factor for determination of success rate (85). Moreover, few studies have made a distinction between treatments of vital pulp and non-vital pulps and combined data have time and again been relayed. Exceptions are the studies of Strindberg (1), Grahnén & Hansson (2), Engström & Lundberg (31), Kerekes & Tronstad (3) Rudner & Oliet (71), Oliet (53), Roane (72), Pekruhn (61), Sjögren et al. (65) where pulpectomized teeth can be discerned from other pulpal diagnoses operated on.

Consequently, the issues in focus for this review, namely the extent to which outcome is affected by the apical extension of instrumentation and filling and the number of appointments to complete the treatment, have not been addressed with a randomized prospective study design. It should be kept in mind, however, that pronouncements to base medical and dental practices on evidence-based research is not very old and has only in recent years started to appear in patient-orientated dental research (86). Nevertheless, it seems reasonable to conclude from published reports that pulpectomy, if carried out under strict and controlled conditions, may result in a very high success rate (87). Reports in the literature also infer that the number of appointments is not a decisive factor and that instrumentation and root filling, if time admits, can be completed in one sitting without jeopardizing the long-term success.

As far as the length of instrumentation is concerned, the results of numerous studies do indicate that it is more favorable to stop short of the anatomic apex than long (1, 2, 88, 89). A most likely reason for this observation is the infection variable. Hence, in the absence of an inadvertently induced wound infection, the wound level ought to be insignificant provided a biocompatible root filling material is used. Nevertheless, it is hard to rationalize, as sometimes advocated, that the apical foramen should be pierced and root canals overfilled with so called puffs. It seems that overfills of this nature only demonstrate the inexactness of the filling technique being used. If such an approach regularly is sought, a fair number of root canals will become unnecessarily overinstrumented and overfilled. Yet, as discussed by Bergenholtz et al. (90), an inadvertent overfilling may not *per se* be harmful or be the immediate cause of an emerging osteolytic lesion. It may instead reflect an unfavorable shaping and lateral extension of the foramen at the apex, thus enhancing the risk of root canal infection both to emerge and to affect the periapical tissue. Small

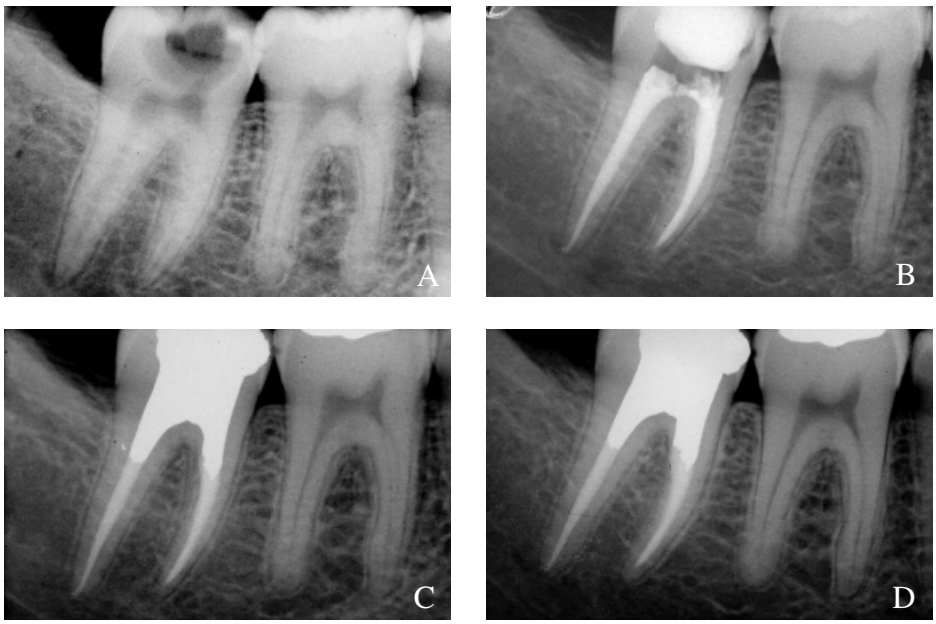

Fig. 3. Pulpectomy of tooth #47 because of a carious exposure of the pulp. (A) Preoperative radiograph showing a small osteolytic lesion on the distal root. (B) Immediate postoperative control showing a small overfill of the distal root. (C and D). Two- and 3-year postoperative control radiographs show normal periapical bone structures and disappearance of the overfill.

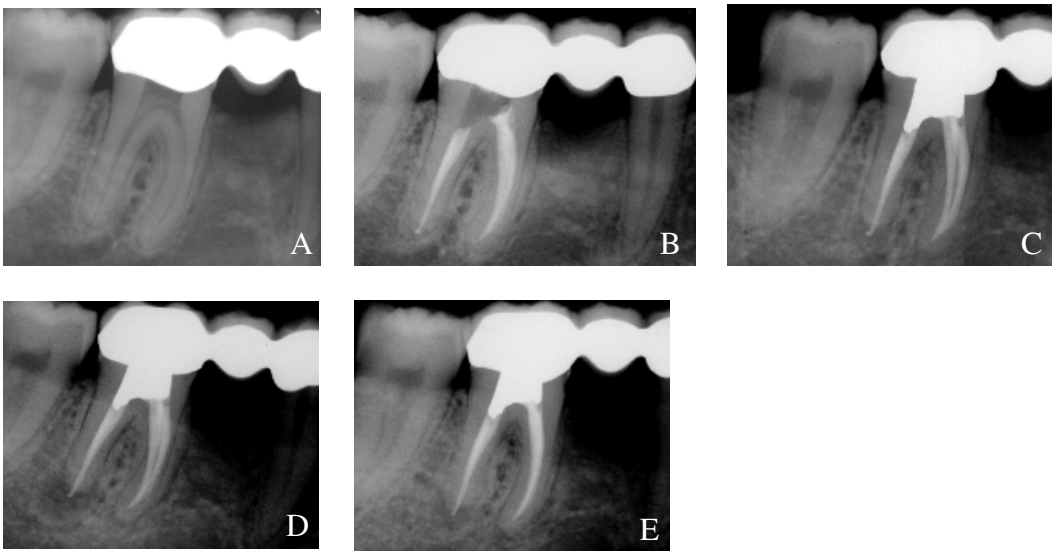

Fig. 4. Pulpectomy of tooth #46 because of a symptomatic pulpitis after completion of bridge reconstruction. (A) Preoperative radiograph. (B) Immediate postoperative control shows a small overfill of the distal root. (C) One-year control radiograph presents with a small osteolytic lesion at the distal root, while normal periapical bone structures remains on the mesial root. (D) The 2-year control radiograph shows a larger radiolucent area. Patient is comfortable and presents with no symptoms suggesting ongoing infection. In the 3-year control radiograph (E) the radiolucent zone associated with the distal root appears reduced. Tooth is comfortable.

extrusion of filling material, although implying a risk of a long-standing foreign body reaction (27), may therefore not appear as a significant variable as long as non-infectious conditions prevail in the root canal system (Fig. 3).

Sjögren et al. (65) confirmed that overfilling had no impact on the prognosis in cases of vital pulp treatment, while it was an important unfavorable factor in cases of primary infected root canals. In that study, 30 roots of teeth with vital pulp were filled with excess of material, and no radiographic signs of apical periodontitis could be noted in any of the cases at the follow-up examinations. Halse & Molven (76) and Molven et al. (91) examined overfilled root canals 10–17 years and 20–27 years postoperatively and observed that periapical lesions recorded early disappeared during later observation periods; in some cases after many years. Periapical healing occurred along with the disappearance of the filling excesses. It is, therefore, possible that some lesions, which become visible after a pulpectomy procedure and in conjunction with overfills, are associated with a non-infectious etiology (Fig. 4). Regardless, deliberate overfilling cannot be justified and should be avoided for the primary reason of not inducing more than necessary tissue toxic, allergenic or foreign body reaction, which in turn may compromise apical wound healing, induce an apical lesion and thereby endanger the possibility of properly assessing the treatment.

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