SUCCESS OF ENDODONTIC THERAPY ON PERMANENT MOLARS AND RECOMMENDATIONS FOR ENDODONTIC THERAPY IN THE NORTH YORK PUBLIC HEALTH DEPARTMENT.

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COMMUNITY DENTAL HEALTH SERVICES RESEARCH UNIT

QUALITY ASSURANCE
REPORT NO. 14

1996

The Community Dental Health Services Research Unit (CDHSRU) is a joint project of the Faculty of Dentistry, University of Toronto and the Community Dental Services Division, North York Public Health Department. It is supported by a grant from the Ontario Ministry of Health (#04170).

The opinions expressed in the report are those of the authors and no official endorsement by the Ontario Ministry of Health is intended or should be inferred.

The frequency of endodontic therapy of permanent teeth has increased substantially in the past 30-40 years, with an increasing proportion of this treatment occurring on the molars and pre-molars rather than anterior teeth (Ingle *et al.* 1985, Farrell & Burke 1989). Performing endodontic treatment on posterior teeth may be more difficult than anterior teeth due to the location of the teeth and their root morphology (Altonen & Mattila 1976, Persson 1982, Ioannides & Bortslap 1983, Friedman *et al.* 1991, Cheung & Lam 1993). Before considering endodontic therapy, the patient and the practitioner should have an idea of the overall probability of success, but studies investigating the success of endodontic treatment of posterior teeth report varying results. Ingle *et al.* (1985) suggested that treated teeth, if properly restored, will be retained as long as vital teeth.

The North York Public Health Department operates a school-based publicly funded dental program that offers basic dental care to children in need. Because the dental program's resources are limited, treatment, prevention, and education are provided based on need which is identified through a screening examination. Using this needs-based approach, North York hopes to allocate its fixed resources most appropriately, achieving the highest level of oral health possible for the greatest number of children. One of the treatment services currently offered is endodontic therapy. However, in order to assess which services are most likely to achieve North York's oral health goals, the expected prognosis of the services they offer should be known. Therefore, we have reviewed the literature to assess the expected rates of success for endodontic therapy of children's permanent posterior teeth.

Background

The pulp of a tooth contains cellular connective tissue and collagen fibres which support blood vessels and nerves. Preserving the vitality of a tooth's pulp is a principle concern of dentistry. Occasionally however, the pulp of a tooth becomes irritated or diseased, resulting in pulpal inflammation and increased intrapulpal pressure which can reduce or halt blood supply to the pulp (Plasschaert 1983a).

In response to pulpal irritation, reparative/secondary dentine or calcified tissue

may be laid down, but in some instances the inflammation is too severe and parts of the pulp may become necrotic. Pulpal inflammation or pulpal necrosis may be followed by the development of apical periodontitis at the apex of a tooth's root(s). This condition results in a loss of bone around the root apices and can lead to destabilization or loss of the tooth. Clinical symptoms of necrotic and periapically diseased teeth can be pain, intraoral swelling, tooth discolouration, tenderness at the apex, tenderness to percussion, and hypo/hypersensitivity to cold or heat (Plasschaert 1983a). The goal of endodontic therapy is to treat the pulp and avoid periapical disease or to heal the condition if it does occur (Eriksen 1991).

When presented with a tooth that is symptomatic of pulpal inflammation, a dentist has a number of treatment options. If the inflammation is limited to a portion of the coronal pulp and the root canal is still vital, a pulpotomy or pulp-capping may be performed. A pulpotomy involves removing some or all of the coronal pulp and covering the remaining pulp tissue with a medicament to maintain its vitality. However, this treatment generally is considered to be temporary; it is usually restricted to deciduous teeth and young permanent teeth with incomplete root formation (Plasschaert 1983b), and may allow these roots to develop fully. More commonly, a pulpally inflamed tooth is either extracted or all of the tooth's pulp tissue is removed and replaced with a filler material. Endodontic therapy is generally favoured for a number of reasons. Aside from the aesthetic consequences of extraction, the dental profession generally believes that retention of permanent teeth is important for the proper development and function of the dental arch. It has been reported that loss of a permanent tooth will result in reduced masticatory efficiency and future periodontal problems (Ingle *et al.* 1985). Early loss of a first permanent molar in children may also result in a loss of arch space as the second molar erupts and drifts mesially, rotation of the second premolar, and supereruption of the opposing molar (Rowe 1966, Zurawic & Weine 1975), but the likelihood and severity of this problem are not well quantified (Woodward & Leake 1993).

Access to the root pulp can be made either through the crown of the tooth (orthograde) or through an incision in the gingiva giving access directly to the root

apex (retrograde). The orthograde procedure is often termed a **root canal** (Ingle *et al.* 1985) and the retrograde procedure is commonly termed **periapical surgery**. Periapical surgery is often performed after initial root canal therapy has failed (Ioannides & Bortslap 1983, Grung *et al.* 1990, Friedman *et al.* 1991, Cheung *et al.* 1993).

The success of endodontic treatment is not guaranteed and other factors besides dental arch development should also be considered. Posterior teeth generally are more difficult for the practitioner to treat than anterior teeth because of restricted access, the increased number of roots per tooth, and curved roots making pulp removal and canal instrumentation difficult (Persson 1982, Cheung & Lam 1993).

In his review of the literature, Gutman (1992) listed 8 factors that affect the probability of success in all cases of endodontic therapy and 12 factors that may influence the probability of success.

Factors reported to affect success or failure of all cases:

(1) Radiographic interpretation
(2) Anatomy of the root canal system and external root anatomy
(3) Thoroughness of debridement and apical level of instrumentation
(4) Degree of apical seal at the cementum-dentin junction
(5) Degree of coronal seal and coronal restoration
(6) Asepsis of treatment regimen
(7) Health and systemic status of the patient
(8) Operator skill/expertise.

Factors reported to possibly affect success or failure of a particular case:

(1) Pulpal status
(2) Procedural accidents; for example, perforations and broken instruments
(3) Crown and root fractures
(4) Periodontal status and disease process
(5) Occlusal discrepancies
(6) Size of periradicular rarefaction
(7) Patient's pain threshold
(8) Level of canal obturation - overfill and overextension
(9) Time of post-treatment evaluation
(10) Degree of canal calcification
(11) Accessory communications
(12) Presence of radicular resorption.

Gutman (1992) noted also that patient age, patient sex, cause of pulpal injury or demise, and tooth location had little impact on the treatment outcome.

Purpose

The purpose of this review is to determine the success rate of initial root canal therapy and periapical surgery on fully developed permanent molars, with special emphasis on the success rates in children. In our opinion, the ultimate measure of endodontic success is whether or not the treated tooth is retained in a disease-free, functional and comfortable state as long as a healthy, untreated tooth. The results of this review will then be used to develop recommendations for when endodontic therapy should be carried out in the teeth of patients whose care is governed by the North York Public Health Department.

Methods

To review the literature and evaluate endodontic therapy we used an evidence-based approach similar to that adopted by the medical sciences. Medical practitioners often base their treatment decisions on community standards and the opinion of experts or leaders in their particular field (Oxman *et al.* 1993). However, expert opinion has been shown to lag behind or be contrary to the scientific evidence (Antman *et al.* 1992). The evidence-based approach to evaluating a specific treatment or test is founded upon the concept that the quality of a study's design is directly related to the conclusions that can be drawn from it. Weak study designs result in weak or questionable conclusions.

Study designs and the types of evidence they provide have been ranked by several agencies including the Canadian Task Force on the Periodic Health Examination (1992) and the United States Agency for Health Care Policy and Research (AHCPR 1993). The AHCPR lists general levels of evidence which were used to assess the studies investigating the success of endodontic therapy.

I (a) Evidence from a meta-analysis of randomized controlled trials
(b) Evidence from at least one randomized controlled trial

II (a) Evidence from at least one well designed study without randomization
(b) Evidence from at least one other type of well-designed quasi-experimental study

III Evidence from well-designed non-experimental studies, such as comparative studies, correlational studies, and case studies

IV Evidence from expert committee reports or opinions and/or experience of respected authorities

Each drop in the level of evidence represents a significant reduction in the strength of the conclusions that can be drawn. Evidence from non-randomized trials provides much weaker evidence than from randomized trials (Guyatt *et al.* 1993), and non-controlled or retrospective studies, i.e. level III, often provide very weak, qualified, or tentative conclusions. Expert opinion cannot be evaluated scientifically and will vary among qualified individuals, and thus is the weakest level of evidence for or against any treatment or test.

To locate articles regarding endodontic treatment of permanent molars, 3 literature searches for studies published from 1966 to 1993 were carried out using the bibliographic database MEDLINE and the following Medical Subject Headings:

(1) (endodontics OR root canal therapy) AND molar, limited to English language articles with human subjects

(2) periapical disease, limited to English language review articles with human subjects

(3) periapical disease, limited to English language articles with human subjects and restricted to articles discussing chemically induced periapical disease, complications, diagnosis, drug therapy, ethnology, epidemiology, prevention and control, or therapy of periapical disease.

The Manual of Undergraduate Endodontics from the Faculty of Dentistry, University of Toronto (Friedman 1993) also was reviewed.

Results of the Literature Search

The three searches listed a total of 368 articles whose titles and abstracts were scanned to identify clinical trials of endodontic treatment of permanent molars, recent

review articles of endodontic treatment, articles addressing endodontic treatment of permanent posterior teeth, and articles reporting the prevalence of endodontic treatment and apical lesions in the permanent teeth. A review of the selected articles and the literature cited within them identified additional articles. Studies reporting results for primary teeth that could not be separated from the results for permanent posterior teeth were excluded. Studies of root canal therapy that reported results from retreated teeth were also excluded, as our focus was on initial therapy. We also did not include articles that discussed individual cases, focused exclusively on specific endodontic procedures without evaluation of the procedure, i.e. "how to" articles, or studied teeth with incompletely developed roots.

Very few studies had reported results specific to permanent molars. More commonly, results were presented for all tooth types combined, along with the proportions of the different tooth types included in the study. Some studies also presented their results according to tooth type allowing for a comparison of outcomes. This review included the results of studies that reported examining molars and/or posterior teeth (molars and premolars), as well as studies that published tooth specific data which included permanent molars.

Of the studies of endodontic success that were identified by the literature search, none were randomized controlled trials (Level I Evidence) or quasi-experimental studies (Level II Evidence). All of the studies were found to be between Level III and Level IV evidence; many were poorly designed retrospective case studies. Because of this poor level of evidence we decided to include all studies of endodontic therapy on permanent posterior teeth, along with a fairly comprehensive summary of their methods, materials, and results.

In total, we located 16 case studies on the success of root canal therapy, which were of three general designs. The best design was prospective (Type A), where the study was proposed and designed before treatment began, allowing procedures and methods to be standardized. Following treatment, the patients were re-examined after a pre-determined length of time (follow-up period). Only three studies used the prospective approach (Shah 1988, Orstavik *et al.* 1987, Pekruhn 1986).

Nine of the case studies of root canal therapy were retrospective, recalling patients who had been treated in university or private clinics during a specified time period and comparing their status at their follow-up examination to their status when treated, as recorded in the clinic's charts (Sjogren *et al.* 1990, Molven & Halse 1988, Matsumoto *et al.* 1987, Barbakow *et al.* 1980, Heling & Kischinovsky 1979, Jokinen *et al.* 1978, Selden 1974, Engstrom & Lundberg 1965, Grahnen & Hansson 1961). This type of case study (Type B) was proposed and carried out some time after all of the treatments had been completed and relies on accurate record keeping to determine the patients status at the time of treatment. The retrospective design is weaker than the prospective design because it lacks standardized methods for selecting patients, treating patients, taking radiographs, and charting.

The remaining studies of root canal therpy were also retrospective, but only included individuals who attended a follow-up examination (Morse *et al.* 1985, Kerekes & Tronstad 1979, Storms 1969, Grossman *et al.* 1964). These studies (Type C) did not report any information regarding individuals who were treated but never re-examined after treatment. Thus, the proportion of patients attending a follow-up examination (follow-up rate) in these studies cannot be calculated. Some studies were based entirely on clinic records, having no follow-up examination specific to the study but just relying on what was recorded on the patients next post-treatment visit(s) to the clinic. This design was the weakest of the three case study designs, as it lacked standardized procedures during the treatment phase and often lacked standardized procedures during the re-examination phase. One may also criticize this design for its selection process which may significantly affect the results due to conscious or unconscious selection of cases based on investigator biases.

After reviewing the literature, we found 11 studies that investigated the success of periapical surgery on permanent posterior teeth. All of the studies were retrospective (Type B and C), using information recorded in the charts of patients treated in the past at university or private practice clinics. Five of the studies were Type B case studies, using a retrospective design and re-examining patients treated during a specific time period (Rapp *et al.* 1991, Grung *et al.* 1990, Ioannides &

Borstlap 1983, Persson 1982, Altonen & Mattila 1976). In two of these studies however, patients were invited to a follow-up examination after the investigators reviewed the clinic records (Rapp *et al.* 1991, Ioannides & Borstlap 1983), and it was unclear if these patients represented all of the possible cases or a selected group. The remaining six studies were Type C, using a retrospective approach that included only cases with follow-up data (Cheung & Lam 1993, Frank *et al.* 1992, Rud *et al* 1991, Friedman *et al.* 1991, Hirsh *et al.* 1979, Ericson *et al.* 1974). Thus, the patient follow-up rates for these six studies could not be calculated.

We also included some population surveys of endodontic status and periapical health. These surveys did not directly assess endodontic success, but give some indication of the frequency of peripical disease and endodontic treatment. We were interested in surveys that reported the periapical health of endondonticly treated and untreated teeth. Because of the constantly changing levels of oral health, we included only surveys that were published after 1983. Based on this selection process, 10 studies were included in this report. Survey evidence is weak for determining endodontic success because it lacks information about when, where, and how treatments were carried out, as well as if a patient's oral health is improving, stable, or deteriorating.

As part of the background and discussion, we also included some literature reviews and discussion papers on endodontic therapy. Although most of these articles provide only level IV evidence, they were included to gain insight into the profession's current opinion about root canal therapy and periapical surgery. Thus, only articles published within the last 10 years were included in our report.

This document was reviewed by two panels. An Internal Staff Panel consisting of three dentists and one hygienist, all of whom work for North York's school-based dental program, initially assessed this report. Concerns and recommendations of the panel were discussed with members of the Community Dental Health Services Research Unit (CDHSRU) and necessary changes were made to accommodate the needs of those providing the dental services. This review then was reviewed by an External Panel of experts consisting of the President of the Royal College of Dental

Surgeons of Ontario, the President of the Ontario Dental Association, an Epidemiologist, an Ethicist, a Paedodontist, a General Practitioner, and a member of the Internal Panel. Concerns and recommendations of the External Panel were discussed with members of the CDHSRU and recommended changes were made. The critical review and its guidelines were than finalized after approval by both the Internal and External Panels.

Summary of Results

General Findings

Although retention of the tooth by means of protection from or reduction of periapical inflammation is the goal of endodontic therapy, there are few methods of assessing a patient's periapical health. Clinical signs or symptoms are variable and not completely specific to this problem, and no saliva or blood borne indicators are known. The most common method used to determine the presence and extent of apical periodontitis is the dental radiograph, where a radiolucency surrounding the root tip is interpreted as a positive indication of periapical disease. The presence, absence, or change in size of a periapical radiolucency following endodontic treatment is often used to define treatment success or failure (Orstavik *et al.* 1986).

Eriksen (1991) recently reviewed the literature surrounding endodontic treatment, and based on a number of Scandinavian cohort studies and surveys, he reported that the prevalence of apical periodontitis increases with age. He also reported that two-thirds of periapical lesions are associated with endodontically treated teeth, but did not specify the tooth type(s) involved. After reviewing the results from studies of root canal therapy performed in speciality or teaching clinics, he estimated success rates for endodontic treatment to be from 85-95%. He also indicated that the success rate for general practice is only 65-75%, but based much of this estimate on the prevalence of endodontically treated teeth with periapical lesions in the population, not retrospective or prospective studies where the patient history is known. Therefore, this estimate should not be used as direct measures of endodontic success. Based on three studies, Eriksen also reported the success rate of periapical surgery performed in specialty clinics to be 85-90%. Unfortunately for

both root canal therapy and periapical surgery, the tooth type studied, the length of the individual studies, and the definition of success were not reported. Therefore, no survival times or differing success rates between tooth types can be assessed. Eriksen (1991) also pointed out that the conclusions that can be drawn from simple comparisons between studies are limited because of a lack of standardized criteria for evaluating apical periodontitis and treatment quality.

Surveys of Periapical Disease and Endodontically Treated Teeth

The prevalence of periapical disease and endodontically treated teeth has changed substantially in the last few decades (Ingle *et al.* 1985, Farrell & Burke 1989). Table 1 summarizes the results of surveys published since 1984 that have used radiographs to investigate the prevalence of endodontically treated teeth and periapical lesions. All of the surveys involve Swedish or Norwegian adults who have received root canal therapy, most of whom were randomly selected from the general population or university clinic records. The results of these surveys indicate that approximately 1-5% of non-endodontically treated teeth appear to have a periapical lesion. Approximately 10-20% of all teeth appear to have been endodontically treated, and about 25-35% of these teeth appear to have a periapical lesion.

Two of the surveys in Table 1 examined some of their participants twice over a number of years (Eckerbom *et al* 1987, 1989, 1991, Petersson *et al.* 1991), producing some data on changes in periapical status over time. Petersson *et al* (1991) reported that of the 82 endodontically treated teeth with periapical lesions witnessed in 1974, 18 (22%) had been extracted, 15 (18%) had been retreated, and 49 (60%) had not received any further treatment when reexamined in 1985. Examination of the 15 retreated teeth, revealed that 10 (67%) showed periapical healing. Of the 49 teeth receiving no further treatment, 19 (39%) of the periapical lesions showed healing, 27 (55%) showed no change or an increase in size, and 3 could not be evaluated. Petersson *et al.* (1991) also reported that of the 25 non-treated teeth with periapical lesions at the 1975 examination, 13 had been extracted, 7 had been root filled, and 5 had been left untreated by the 1985 examination. At the 1985 examination it was

found that healing had occurred in 5 of the 7 treated cases and 2 of the 5 untreated cases. Based on these radiographic findings, it appears that healing without intervention may occur but the sample sizes are too small to determine any accurate rates for this process.

Eckerbom *et al.* (1987, 1989, 1991) recorded the endodontic and periapical status of the same adults in 1975-76 and 1980-82. The sample sizes of this study are greater than those of Petersson *et al* (1991) but their results also do not allow definite conclusions to be drawn due to missing data and the fact that the data are presented from both a "tooth" and "root" perspective. At their first examination, they found 255 teeth (314 roots) with periapical lesions, 168 teeth were endodontically treated and 87 were untreated teeth. At the second examination they reported that 172 of the roots with periapical radiolucencies had healed, 10 had decreased in size, 122 had remained the same size, and 10 had increased in size. Of the 142 lesions still present (10+122+10), 59 were associated with untreated roots. Therefore, some of the roots from the 87 untreated teeth must have healed. However, it is unclear how many and which of the untreated teeth received treatment between the two examinations.

The surveys have also reported a number of associations between age, endodontic treatment, and periapical radiolucencies (disease). Studies have shown that both the prevalence of endodontically treated teeth and the prevalence of periapical radiolucencies increases with age (Bergstrom *et al.* 1987, Odesjo *et al.* 1990, Petersson 1991). Although a 1983 survey published by Hugoson *et al.* (1986) also showed a positive association between age and the prevalence of endodontically treated teeth, an earlier survey by the same authors (1973) showed no relationship. Odesjo *et al.* (1990) reported that the percentage of endodontically treated teeth with periapical lesions was negatively associated with age, decreasing from 50.0% for ages 20-29 to 20% or less for ages 50 and over.

The surveys also suggest that restorative quality may affect treatment outcomes. A number of surveys have reported a negative correlation between the prevalence of inadequate root fillings and the prevalence of periapical lesions (De Cleen *et al.* 1993; Odesjo *et al.* 1990, Eriksen *et al.* 1988, 1991, Bergstrom *et al.* 1987;

Petersson *et al.* 1986a, 1989, Allard & Palmqvist 1986). These surveys also found that 60% or more of root fillings were inadequate and more than 40% of roots were inadequately sealed (De Cleen *et al.* 1993; Eckerbom *et al.* 1987, 1989; Eriksen *et al.* 1988; Petersson *et al.* 1986a, 1989; Odesjo *et al.* 1990, Allard & Palmqvist 1986).

However, one should be cautious when interpreting the results of dental surveys. Radiographs of endodontically treated teeth cannot give us any definitive information about the significance of a periapical radiolucency because it is unknown how long ago the endodontic treatment took place, whether or not a radiolucency was present at the time of treatment, or if the radiolucency is increasing or decreasing in size. Definite conclusions also should not be drawn about factors that are associated with a specific outcome or level of oral health, such as patient age.

Case Studies of Initial Root Canal Therapy

The methods of sixteen case studies of root canal therapy that included posterior teeth are summarized in Table 2a according to the decade of treatment. Follow-up periods among and within studies were highly variable, and most were relatively short, i.e. 5 years or less. The studies also reported low rates of patient follow-up. Regardless of the length of the follow-up, few studies had re-examined greater than 60% of the original cases. For Type C studies rates of patient follow-up cannot be assessed as they only reported data on individuals that attended a follow-up examination.

Success Rates

Success rates of intial root canal therapy from the sixteen studies that have included molars are summarized in Table 2b. Results from these studies do not indicate that the rates of success have improved much over time, although the large degree of variation in the length of the follow-up periods makes comparisons difficult. Rates of success in the 1980's may appear slightly higher, but these studies are of the shortest duration.

Loss of treated teeth in the study groups was not included by any of the studies

when calculating the success/failure rates. Some studies reported the number of teeth lost through extraction, but excluded them from further analyses (Sjogren *et al.* 1990, Molven & Halse 1988, Orstavik *et al.* 1987, Pekruhn 1986, Barbakow *et al.* 1980, Jokinen *et al.* 1978, Grahnen & Hansson 1961). Reasons for excluding these data often were not given (Sjogren *et al.* 1990, Orstavik *et al.* 1987, Barbakow *et al.* 1980, Jokinen *et al.* 1978, Grahnen & Hansson 1961) or the authors reported that the losses were unrelated to the endodontic treatment (Molven & Halse 1988, Pekruhn 1986). For the remaining studies, it is possible that they either had no cases of tooth loss, did not report tooth loss, or did not include these cases when reporting results or selecting cases i.e. Type C studies.

Each study's measurement of treatment outcome always included the tooth's radiographic appearance and often included the presence or absence of clinical symptoms. However, the definitions of success varied among the studies and are summarized in Table 2b. Because many studies reported that the success of root canal treatment is often higher if no periapical lesion is present at the time of treatment, the success rates have been classified according to the pre-operative periapical status of the tooth.

Many studies report a success rate for root canal treatment of 90% or more if no periapical lesion (radiolucency) existed at the time of treatment, but this rate decreases 10-20% if a periapical lesion was present. However, it is more appropriate to consider these findings as short-term estimates of the rate of periapical healing following root canal therapy rather than long term success rates. Most of the studies, especially those that were prospective, had a relatively short follow-up periods, which along with poor rates of patient recall, exclusion of teeth lost due to extraction, and varying definitions of success, make it impossible to calculate an accurate long term estimate of treatment success.

When studying posterior teeth, one should also consider whether the rates of success are reported on a per root or per tooth basis. If it is assumed that all posterior teeth have at least three root canals and that only one root per tooth fails, the success rate per tooth will be less than the success rate per root. For example,

if 300 roots from posterior teeth are treated, this may represent only 100 teeth. Therefore, if 30 roots fail, the success rate per root will be 90% (270/300), but if each of these roots is on a different tooth the success rate per tooth will only be 70% (70/100).

Influence of Patient Age

The studies in Table 2a include a substantial range in subject age but only a few of the studies used their data to assess any possible effect of age on treatment outcome. Although they did not publish the supporting data, Grossman *et al.* (1964) reported a direct relationship between patient age and periapical repair. Storms (1969) also reported slightly greater success in older than younger patients, but no statistical test results were provided. Heling and Kischinovsky (1979) reported that "repair was slightly higher in younger patients", but did not publish their data or any statistics to support their claim. Jokinen *et al.* (1978) and Kerekes and Tronstad (1979) reported no significant effect of age on the treatment success rate, although Kerekes and Tronstad (1979) did not publish any age related data. Results from Barbakow *et al.* (1980) also did not support any relationship between age and success rate.

A separate article by Molven *et al.* (1985) discussing the same data as Molven and Halse (1988), reported a relationship between patient age and the extraction of endodontically treated teeth. Based on the 55% of the patients who attended the follow-up exam, the authors reported 83% of the endodontically treated teeth were still present after 10-17 years even though approximately one third of the patients attending the follow-up exam were missing at least one endodontically treated tooth. However, tooth retention was not evenly distributed across all age groups. All treated teeth in the youngest age group, 26-35 years, were still present, but loss of treated teeth increased steadily with age.

Influence of Tooth Type

Table 2b does not provide treatment outcomes for posterior teeth specifically, only studies including posterior teeth. However, some of the studies did publish their data by tooth type or position, or examined their data to determine if success varied

according to tooth type or position. When outcomes for posterior and anterior teeth were compared, some studies reported poorer outcomes in anterior teeth (Grahnen Hansson 1961, Engstrom & Lundberg 1965, Jokinen *et al.* 1978, Molven & Halse 1988) and others reported poorer outcomes in posterior teeth (Barbako *et al.* 1980, Shah 1988). A number of the studies reported no relationship between the treatment outcomes and the tooth type or position (Storms 1969, Kerekes & Tronstad 1979, Pekruhn 1986). However, many studies did not test for any statistically significant difference among tooth types or had sample sizes that were too small for valid conclusions to be made.

Tables 3 and 4 were created to summarize the results of all the studies that published results according to tooth type or position. Studies that published results for specific tooth types in the mandible and maxilla are listed in Table 3. Studies that only published their results for posterior versus anterior teeth are listed in Table 4. We have also calculated the mean and weighted mean, according to sample size, of the success rates reported by the authors in Tables 3 and 4, plus Table 4 includes a mean and weighted mean for the results of Tables 3 and 4 combined.

The findings in Tables 3 and 4 suggest that little, if any, consistent difference exists between the reported success of root canal therapy in anterior and posterior teeth, or between the reported success rates of the maxilla and mandible. Table 3 does show very low mean reported rates of success for mandibular central and lateral incisors, but these are based on only two studies, Jokinen *et al.* (1978) and Storms (1969).

Influence of Technique

Techniques used to seal and fill the treated roots have also been addressed as potential factors affecting the outcome of root canal therapy. Two studies reported that inadequately sealed teeth were less successful than those that were adequately sealed (Kerekes & Tronstad 1979, Molven & Halse 1988). A number of the studies also reported that teeth filled to the level of the root apex resulted in better outcomes than overfilled teeth (Grahnen & Hansson 1961, Heling & Kischinovsky 1979, Kerekes & Tronstad 1979, Barbakow *et al.* 1980, Sjogren *et al* 1990) or underfilled

teeth (Kerekes & Tronstad 1979, Barbakow *et al.* 1980, Sjogren *et al* 1990). Engstrom and Lundberg (1965) reported the best results occurred when the root was filled to within 1-2 mm of the apex. Storms (1969) and Jokinen *et al.* (1978) reported that teeth with underfilled roots or roots filled flush with the root apex had significantly better outcomes than teeth with overfilled roots. Molven and Halse (1988) reported that teeth with underfilled roots had better outcomes than teeth with overfilled roots or teeth with filling that were level with the root apex.

Influence of Pre-treatment Tooth Status

Periodontal and pulpal condition at the time of treatment have also been reported as factors associated with root canal success. Matsumoto *et al.* (1987) reported that their success rate was only 57% when periodontal pockets of greater than 2 mm existed but this increased to 90% when periodontal pockets were 2mm or less. They also reported that teeth with both adjacent teeth present had a greater success rate (84%) than teeth with no adjacent teeth (69%) or one adjacent tooth (64%). Sjogren *et al.* (1990) reported no significant influence of periodontal pockets on the outcome of root canal treatment, but did report increased success rates for teeth with vital pulps at the time of treatment compared to teeth with necrotic pulps. Results from Orstavik *et al.* (1987), Jokinen *et al.* (1978), and Grahnen and Hansson (1961) also suggested that the prognosis is better for teeth with vital pulps, but the results of Barbakow *et al.* (1980), Kerekes and Tronstad (1979), Heling and Kischinovsky (1979), and Grossman *et al.* (1964) found no relationship. Storms (1969) reported that vital teeth were more successful but this result is confounded by the presence of periapical radiolucencies surrounding the roots of all non-vital teeth at the time of treatment.

Influence of Tooth Fracture

Although not addressed by most studies, tooth fracture following endodontic therapy can have an impact on tooth survival. Based on survival analysis of 190 posterior teeth that were treated by 56 general practitioners, Hansen and Asmussen (1990) reported that regardless of cavity type (MO, DO, or MOD) 93%, 87%, and 72% of composite resin restored teeth will survive 3,5, and 10 years respectively.

However, significant differences existed between the chemically cured and light cured resins, with 92% of the chemically cured surviving 5 years but only 59% of the light cured surviving 5 years. In a similar study of 1584 posterior teeth treated by 91 general practitioners, Hansen *et al.* (1990) found the survival of teeth with MO and DO amalgam restorations to be 85-95%, 80-90%, and 65-75%, after 3, 10, and 20 years respectively. Survival of teeth with MOD amalgam restorations was approximately 80-90%, 55-65%, and 30-40% after 3, 10, and 20 years respectively. These rates of survival should not be confused with the expected rates of restoration survival. Although a failed restoration may be replaced, the studies discussed here are reporting rates of **tooth** fracture following endodontic therapy. It should also be noted that some of the cases of tooth fracture may have occurred prior to endodontic treatment but were noticed after treatment.

Case Studies of Periapical Surgery

Table 5a summarizes the studies that investigated the outcome of periapical surgery. Most of these studies again focused on periapical status, assessed using radiographs to determine the treatment outcome, and the vast majority of cases involved the retreatment of a tooth that had received non-surgical endodontic therapy.

Success Rate

Results of the periapical surgery studies are summarized in Table 5b. As was the case with the studies of root canal therapy, the method of reporting extracted teeth varied. Three studies reported the number of teeth that had been extracted and included these teeth in their data analysis (Ioannides & Borstlap 1983, Altonen & Mattila 1976, Ericson *et al.* 1974). One study reported that 14 roots were extracted following the study, but these teeth were not included in the data analysis (Friedman *et al.* 1991). Two studies reported excluding cases when tooth status was compromised due to crown fracture, root fracture, periodontitis, or lateral perforation during the placement of a post (Frank *et al.* 1992, Rud *et al.* 1991). The remaining five studies may not have had any extracted teeth, may not have reported any

missing teeth, or may not have included any cases of extraction in their study or data analysis. When not reported, we have chosen to list the number of extractions as "not reported" in Table 5b, rather than assume that zero teeth were lost to extraction.

Results in Table 5b are summarized according to the amount of periapical healing evident on radiographs that took place following surgery, and these rates ranged from 47-72%. Many of the studies chose to report only the degree of periapical healing, opting not to report rates of success (Rapp *et al.* 1991, Rud *et al.* 1991, Ioannides & Borstlap 1983, Hirsh *et al.* 1979, Altonen & Mattila 1976, Ericson *et al.* 1974). The remaining studies defined successful outcomes as those with complete healing, except Grung *et al.* (1990), who included incomplete healing, and Friedman *et al.* (1991), who included clinical symptoms, when calculating their success rates. Thus, according to their own definitions of success, Grung *et al.* (1990) reported their success rate to be 87% and Friedman *et al.* (1991) reported that 44% of their cases were successful.

Influence of Patient Age

Patient age and its relationship with periapical healing varied among studies. Rapp *et al.* (1991) reported that the rate of periapical healing may increase with age but Hirsch *et al.* (1979) reported that patients below 35 years of age showed greater healing than those aged 35 years or more. Friedman *et al.* (1991) and Grung *et al.* (1990) found no relationship between age and treatment success.

Influence of Tooth Type

Table 5b is divided into two sections, studies that included posterior teeth but reported their results for all tooth types combined, and studies that focused on posterior teeth or reported their findings for posterior teeth separately from anterior teeth. From these results, it is difficult to determine if the rates of healing differ among tooth types. Rud *et al* (1991) reported a tendency toward poorer healing in canines and incisors, but Ericson *et al.* (1974) reported slightly better healing in canines than other tooth types. Halse *et al.* (1991) reported no difference between the healing times of the different tooth types, and in a study of only premolar and molar teeth, Friedman (1991) reported no difference in the success of periapical surgery on

first or second premolars or molars.

Influence of Technique

The materials and techniques used to seal and restore the roots varied among and within the studies included in Tables 5a and 5b. Grung *et al.* (1990) reported that failure was much higher in retrograde filled teeth (28%) than orthograde filled teeth (4%). Hirsch *et al.* (1979) found that apicoectomies with retrograde fillings showed greater success (49%) than apicoectomies with curettage and no retrograde filling. However, both Rapp *et al.* (1991) and Ericson *et al.* (1974) reported that the presence or absence of a retrofilling had no effect on treatment success. Rapp *et al.* (1991) also reported that teeth with a permanent restoration were more successful than teeth without permanent restorations and that no difference existed in the success of roots retrofilled with either amalgam, IRM Cement (L.D. Caulk, Milford, D.E.) or EBA Alumina Cement (Teledyne Getz, Elk Grove Village, IL).

Rud *et al.* (1991) reported significantly greater rates of complete healing for teeth with composite retrograde restorations compared to amalgam, with a much greater proportion of incomplete healing or scarring in the amalgam group. Using a retrospective design, their study compared the outcomes of individuals treated with amalgam versus individuals treated with composite resin. However, the follow-up period for the amalgam cases was always 1 year whereas the follow-up period for the composite cases ranged from half a year to a full year. Rud *et al.* (1991) also selected cases non-randomly from clinic records, excluding composite resin cases for reasons such as root fracture; methods of case selection were not reported for the amalgam cases.

Frank *et al.* (1992) also reported very high failure rates for periapical surgery with amalgam retrograde fillings, but the study design leaves the results open to question. The study is similar that of Rud *et al.* (1991) but has a follow-up period of 10 years or more and does not include a comparison group with a filling material other than amalgam.

Over time, it is likely that the techniques employed may have changed and that this may affect the success rates. However, the results in Table 5b do not show

any noticeable difference in the rates of healing according to the decade of treatment. Rapp *et al.* also addressed this question and reported no difference in the success rates of cases treated from 1965-75, 1976-85, or 1986 and later.

Influence of Pre-treatment Tooth Status

Although a periapical lesion is almost always present in cases of periapical surgery, some investigators have studied the relationship between the size of the lesion and its prognosis. Ericson *et al.* (1974) found no difference in the rate of healing between cases with greater than or less than 5mm of periapical destruction at the time of treatment. Grung *et al.* (1990) reported that the success rate of cases with 2-5 mm of bone loss at the time of treatment did not differ from those cases with greater than 5 mm or less than 2mm of bone loss. However, Hirsch *et al.* (1979) reported that lesions with less than 5 mm exhibited better healing than lesions larger than 5 mm, but this was not a major predictor of healing frequency. Altonen and Mattila (1976) found that periapical healing was less likely if periapical lesions were present around the roots of other teeth, although one could argue that this is a reflection of the patients' overall oral health rather than the treatment effectiveness.

Other Factors

Other factors affecting the outcome of periapical surgery have also been addressed. The presence of clinical symptoms such as swelling and/or tenderness to percussion has been associated with a reduction in periapical healing (Friedman *et al.* 1991). Oro-antral communication was reported to have no effect on the success of apicoectomies of posterior teeth (Ericson *et al.* 1974).

Discussion of Findings

In general, the studies included in this review reported that root canal therapy has a success rate of 80-90%, but this is reduced by 10-20% if a periapical lesion is present at the time of treatment. However, these success rates are defined mostly by radiographic appearance of the root apex, and may be more accurately described as the rates of periapical healing following root canal therapy. The rate of complete healing following periapical surgery appears to be 50-70%. All of these rates can only be considered short term-estimates as few cases have been studied for periods longer than 5 years.

When evaluating a medical procedure it is very important that all patients who entered the trial are accounted for at the studies conclusion. Substantial loss of patients during the study leaves the validity of the results open to question. One can assess if the study's losses to follow-up were excessive by assuming that all losses in the experimental group did poorly and all losses in the control group did well. If, when the results from these follow-up losses are imputed, the conclusions differ from the conclusions drawn when follow-up losses are not included, the strength of this evidence is significantly reduced (Guyatt *et al.* 1993).

If we define success as retention of the treated tooth in a disease-free, functional, and comfortable condition and adopt the medical profession's policy of treating all follow-up losses in the experimental group as failures, the rates of success would be significantly reduced. Rates of patient follow-up generally were very low and most studies did not include extracted teeth when calculating their rates of success. Some studies excluded teeth due to procedural accidents (e.g. perforations), crown and root fracture, and periodontal status. Although not all of these failures may have been a direct result of periapical disease or the endodontic treatment, one could argue that they are ultimately related to the overall endodontic treatment plan. A survey of endodontic failures by Johnson *et al* (1976) reported that over half were the result of fracture of the tooth's crown. Gutman (1992) suggested that these are all factors that may influence the success or failure of a particular case. Thus, these cases could be defined as failures when assessing the treatment's overall success rate.

For example, if we examine the data from Molven and Halse (1988), we find that they report a success rate of 90% for cases without a periapical radiolucency and 69% for cases with a periapical radiolucency. However, these rates were calculated using only 83% of the cases present at the recall exam; 17% of the treated teeth had been extracted. Thus, if we assume extracted teeth to be failures, the success rate for teeth with no periapical radiolucency drops to 75% (90% x 0.83). For teeth with a pre-treatment periapical radiolucency, the success rate would drop to 57% (69% x 0.83) which is very similar to the fate of the endodontically treated teeth that were re-examined in the survey by Peterson *et al.* (1991). Their survey reported that after 10 years, 22% of the teeth were extracted (failures), 18% were re-treated (failures), and 60% had not received any additional treatment (successes). If we assume all patients who do not attend follow-up examinations to be failures, the success rates of Molven and Halse (1988) fall below 50%.

The strong reliance on radiographs to determine treatment success should also be questioned. Although some studies have strongly supported the relationship between the radiographic image and the extent of periapical disease, other studies have not reported such a strong relationship. Using data from Brynolf (1967), Orstavik *et al.* (1986) reported a strong correlation between radiographic appearance and histologic appearance of incisors when grouped according to their periapical index. Rohlin and Akerblom (1992) also reported that the combined sensitivity and specificity of panoramic radiographs, periapical radiographs, and clinical examinations to be high when diagnosing periapical lesions. However, this study used a consensus of opinion regarding the radiographic images as their "gold-standard" for the actual presence or absence of a lesion. Therefore, the actual presence or absence of periapical disease was unknown and the values for sensitivity and specificity are questionable. Other studies have reported the sensitivity of radiographs for detecting teeth in need of endodontic treatment to be quite low (Petersson *et al.* 1986b, Tidmarsh 1987), and have shown that radiograph-based diagnoses and treatment decisions for endodontic therapy vary considerably among individual practitioners (Tidmarsh 1987, Gutman 1992). When diagnosing a patient's

need for endodontic treatment, Steiman (1991), Himel (1991), and Gutman (1992) have all suggested that radiographs should only be used to corroborate other findings, such as the patient's complaints and symptoms.

The use of radiographs to determine success is questionable also in cases where no periapical radiolucency exists at the time of treatment. In these cases, a high rate of success is virtually guaranteed and one might wonder why, if the absence of a periapical radiolucency following treatment is defined as success, did so many teeth without radiolucencies receive endodontic therapy? One might argue that the appearance of a periapical radiolucency where no pre-treatment radiolucency previously existed is evidence that the treatment itself has resulted in periapical disease.

Study design and level of evidence should also be considered when determining the success of a clinical procedure. Unfortunately all of the studies lack any type of control group. None of the studies investigated the healing rates of periapical lesions when left untreated or the outcome when teeth with clinical symptoms, but no periapical radiolucency, were left untreated. Leaving periapical disease untreated would probably be viewed by many dentists and patients as unethical, but without a proper comparison group to assess healing rates of untreated teeth the relative value of the treatment cannot be assessed.

It appears that a pseudo-controlled study with relatively short period of recall is plausible and should be considered. Studies and surveys suggest that some adults have periapical radiolucencies but no clinical symptoms. Without clinical symptoms, it is likely that many of these cases would not be treated as the individuals would not visit a dentist. Study of such patients may help determine the outcome of periapical lesions left untreated. The results of Petersson *et al.* (1991) and Eckerbom *et al.* (1987, 1989, 1991) suggest that some periapical lesions may heal, decrease in size, or remain the same size without endodontic intervention. Therefore, the success rates of root canal therapy and periapical surgery may be lower than most studies have reported.

Most of the studies also lacked standardized procedures for treating and

radiographing the patients, with the procedures being performed by many different operators. These factors make if difficult to accurately compare results among and within the studies. Without standardized and controlled procedures it is impossible to determine the reasons for success or failure. Higher failure rates in one study may be the result a number of factors such as the materials used, the specific procedure employed, operator skill, or radiographic technique. Therefore, one should be cautious when interpreting the results of studies lacking a standard treatment protocol.

Aside from study design, a number of other factors were also reported to have a possible influence on the outcome of root canal therapy and periapical surgery. Patient age and tooth type appear to have no consistent effect on the success rate of root canal therapy or periapical surgery. Therefore, the results from treatment of all tooth types in adults may be applicable to permanent posterior teeth in North York children.

Success of root canal therapy appears related to the quality of restorative care received and the health of the tooth at the time of treatment. Higher rates of success were found when the procedure was performed on vital teeth and were found to be reduced if the root canal is overfilled. Rud *et al.* (1991) reported success of periapical surgery may be greater if a composite resin retrograde restoration is placed rather than amalgam, but a literature review by Dorn and Gartner (1991) suggested that reinforced IRM is their material of choice at present. Dorn and Gartner (1991) did not recommend composites or glass ionomers as root end filling materials because of the difficulty of avoiding moisture contamination. For orthograde restorations, the risk of tooth fracture appears to be quite high if the restoration involves more than two surfaces.

Due to the quality of the studies investigating endodontic therapy, it may be difficult to determine when and if treatment should be carried out. Ingle *et al* (1985) suggested that the decision of whether or not to treat should be based on the answer's to the following seven questions.

(1) Is the tooth needed or important: Does it have an opponent? Will it some day serve as an abutment for a prosthesis?
(2) Is the tooth salvageable or is it so badly destroyed it cannot be restored?
(3) Is the entire dentition so completely broken down it would be virtually impossible to restore?
(4) Is the tooth serving aesthetically, or would the patient be better served by its extraction and a more cosmetic replacement?
(5) Is the tooth so severely involved periodontally that it would be lost soon for this reason?
(6) Is the patient an appreciative dental patient who truly wants to save his teeth, or is he interested only in extraction?
(7) In the dentist capable of treating the case or are his (her) abilities so limited in this area of practice that he (she), personally, should not undertake the treatment?

Most of the questions posed by Ingle *et al.* (1985) do not relate to factors associated with treatment success, but address whether or not the procedure is judged to be worthwhile by the patients and practitioner. If after addressing these questions the practitioner and patient feel endodontic therapy is worthwhile, they should assess the probability of success after considering the numerous factors that can possibly affect the treatment outcome.

Farrell and Burke (1989) have suggested that endodontic treatment is contraindicated if the practitioner does not have adequate access to the area in question, if the patient has poor oral hygiene and is poorly motivated, if unsuitable medical conditions exist, or if the roots are very curved or resorbed. The practitioner should also consider if the tooth will be restorable following endodontic therapy, the status of the periodontal tissue and alveolar bone support, the importance of the tooth in relation to the total treatment plan, the cost of the treatment as well as the subsequent restoration, and how interested the patient is in saving the tooth (Johnson *et al.* 1976, Friedman 1993).

Conclusion

Due to a lack of definitive evidence, conclusions about the long-term success rates for endodontic therapy, and the factors affecting the success rates, could not be drawn. Reasons for this lack of evidence include, but are not limited to, the following:

(1) no controlled studies exist to determine the rate of healing expected without intervention;

(2) studies have used different methods, materials, and definitions of success;

(3) studies and individual cases vary in the length of time between initial treatment and re-examination, with very few follow-up periods of greater than 5 years;

(4) rates of patient follow-up are low and extracted teeth often are not reported or are excluded from the data analysis;

(5) the validity of using radiographs alone to assess periapical health and treatment outcome is questionable.

In general, it appears that periapical health may be achieved over a short term in as many as 80-90% of root canal cases with no periapical radiolucency at the time of treatment. Treatment prognosis appears to be directly related to the pre-operative health of the tooth and the surrounding tissues. Short term rates of periapical healing for root canal cases with a pre-treatment periapical radiolucency or for periapical surgery cases may be as high as 60-70%. However, these rates may be considerably lower if one considers the quality of the studies and if one defines success as retention of a disease-free, functional, comfortable tooth.

Recommendations for Endodontic Therapy in Permanent Posterior Teeth

The recommendations for diagnosis and treatment in this area are based on opinion published in the literature, opinions of the internal and external panels, and published guidelines of the University of Toronto. This constitutes Level IV evidence as discussed in the Methods (p.4).

Diagnosis

A dentist may consider endodontic therapy if a patient has one or more of the following **primary indicators**.

1) Pain which is localized to one tooth and has been of increasing intensity and/or frequency. This pain may be spontaneous or may result from hot or cold stimuli, percussion, pressure (mastication), or tenderness at the apex.

2) Swelling related to the apex, a fistula, or cellulitis.

3) A large open carious lesion or secondary decay associated with an existing restoration.

Endodontic therapy should be more strongly considered if, along with one or more of the primary indicators, any of the following **secondary indicators** are present:

a) presence of a crown or deep restoration which approaches the pulp;

b) a known history of pulp exposure;

c) tooth mobility;

d) a periapical radiolucency;

e) presence of a failed (e.g cracked, partially missing) restoration;

f) internal root resorption;

g) coronal tooth fracture or non-vertical root fracture.

Following the initial assessment, the **contraindications** for endodontic therapy are:

General Contraindications

- the dentist does not obtain informed consent[1]
- patient compliance with the treatment regime is not expected e.g. patient not expected to return for further visits

Specific Contraindications

- not enough tooth tissue is present to support an adequate restoration
- severe periodontitis is present resulting in a lack of bone support or compromised bifurcation
- there is vertical fracture of the tooth involving the root
- the tooth has never had, and never will have, any masticatory function (e.g. no opposing tooth), or will never serve as an abutment tooth for a prosthetic device
- following extraction of the pulpally involved tooth, an unerupted or erupted tooth will move into the space. In the case of a pulpally involved first permanent molar, the best time for extraction is before the second permanent molar has erupted, preferably before one-third of the second molar roots have formed and while the crypts are still covered by bone. This usually occurs between the ages of 8.5 and 10.5 years (Houston & Tulley 1986, Jones & Oliver 1994).
- periapical surgery is not recommended for posterior teeth in North York children

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[1] "Informed consent under the Act means that before agreeing to the treatment, the person making the treatment decision receives information that a reasonable person in the same circumstances would want about:

- the material effects, risks and side effects of the proposed treatment, and
- alternative courses of action, and
- the consequences of having or not having the treatment" (Royal College of Dental Surgeons of Ontario 1995).

TABLE 1. Radiographic findings of surveys published since 1984 that report the prevalence of endodontic treatment and apical lesions in the general population.

Study	Age (years)	Type of Teeth Examined	# of Teeth Examined	# of Endo-Treated Teeth (%)	% Non-Endo Teeth Periapical Lesions	% Endo Teeth with Periapical Lesions
De Cleen *et al.* 1993	≥ 20	All Teeth	4196	92 (2)	5.2	39.2
Odesjo *et al.* 1990	≥ 20	All Teeth	17430	1492 (9)	0.9	24.5
Bergstrom *et al.* 1987	21-60	All Teeth	6593	430 (7)	1.2[a]	35.6[a]
Eriksen *et al.* 1988	35	All Teeth	3917	133 (3)	0.5	25.6
Eriksen & Bjertness 1991	50	All Teeth	2940	175 (6)	1.5	36.6
Petersson *et al.* 1989[b]	≥ 20	All Teeth	17181	3618 (21)	3.8	24.2
Eckerbom *et al.* 1987, 1989, 1991[c]	≥ 20	All Teeth	4889	636 (13)	1.9	26.4
			4692	689 (15)	3.0	21.5
Allard & Palmqvist 1986	≥ 65	All Teeth	2567	452 (18)	6.1	27.0
Hugoson *et al.* 1986	≥ 3	All Teeth	23290[d]	2086[d] (9)	1.2[d]	19.4[d]
Petersson *et al.* 1986	20-60	Molars, Premolars	4985	650 (13)	2.4	34.6

a) estimate based on the percentage of affected roots and the number of peraipical lesions
b) study of adults requiring "substantial care"
c) examined individuals twice over 5-7 year period
d) calculated from the age specific means and sample sizes provided

TABLE 2a Retrospective and prospective studies of initial root canal therapy that included posterior teeth - study design.

Study by Decade Treatment was Provided	Study Type	Patient Age (yrs)	Patients Treated by	Follow-up Period (yrs)	Patients Attending Follow-up Exam (%)
1980s					
Shah 1988[a]	A	10-60	Principle Investigator	2	55
Matsumoto *et al.* 1987[a,b]	B	??	University Staff	2-3	38
Orstavik *et al.* 1987[b]	A	≤20-80	Dental Students	1 2 3 4	67 61 56 32
Pekruhn 1986[a,b]	A	??	Principle Investigator	1	81
1970s					
Sjogren *et al.* 1990	B	28-82	Dental Students	8-10	46
Morse *et al.* 1985[a]	C	14-75	Principle Investigator	0.5-4	??
Barbakow *et al.* 1980	B	10-80	General Practitioners	≥ 1	60
Kerekes & Tronstad 1979	C	10-80	Dental Students	3-5	84
1960s					
Molven & Halse 1988	B	??	University Clinic	10-17	55
Heling & Kischinovsky 1979[a]	B	9-75	Dental Students	1-16	13
Jokinen *et al.* 1978[c]	B	16-75	University Clinic	2-7	46
Selden 1974[a]	B	??	Principle Investigator	0.5 1.5	50 11
Storms 1969[a,c]	C	<6-79	Dental Students	1	??
1950s or earlier					
Engstrom & Lundberg 1965[a]	B	??	Dental Students	3.5-4	74
Grossman *et al.* 1964[a]	C	??	Dental Students	1-5	??
Grahnen & Hansson 1961	B	??	Dental Students	4-5	44

a) year of treatment not provided by authors but was estimated based upon year of publication and length of follow-up period
b) patient follow-up % not reported, % of teeth or roots examined at follow-up is presented
c) results also include pulpectomies

TABLE 2b Retrospective and prospective studies of initial root canal therapy that included posterior teeth - study results.

Study by Decade Treatment was Provided	Follow-up Period (yrs)	Definition of Success	Sample Size R=roots T=teeth	Successful cases (%) according to presence (+) or absence (-) of pre-operative periapical radiolucency		
				+	-	Total
1980s						
Shah 1988	2	no symptoms & no or reduced radiolucency	132 T	n/a	89	89
Matsumoto *et al.* 1987	2-3	no symptoms & no or reduced radiolucency	85 T	88	67	75
Orstavik *et al.* 1987	1	no or slight radiolucency	546 R	n/a	n/a	82
	2		493 R	n/a	n/a	92
	3		451 R	n/a	n/a	94
	4		259 R	n/a	n/a	96
Pekruhn 1986	1	no symptoms & no radiolucency	889 T	98	89	95
1970s						
Sjogren *et al.* 1990	8-10	no radiolucency, except around excess filler	573 R	97	86	93
Morse *et al.* 1985	0.5-4	no or greatly reduced radiolucency	211 T	n/a	79	79
Barbakow *et al.* 1980	≥ 1	no symptoms & no radiolucency	332 T	n/a	n/a	87
Kerekes & Tronstad 1979	3-5	no radiolucency, except around excess filler	670 R	92	84	90
1960s						
Molven & Halse 1988	10-17	no or small radiolucency	441 R	90	69	79
Heling & Kischinovsky 1979	1-16	no symptoms & no or arrested radiolucency	57 T	92	72	81
Jokinen *et al.* 1978[a]	2-7	no symptoms & no radiolucency	2459 R	61	38	53
Selden 1974	0.5	no or reduced radiolucency	2298 T	96	94	94
	1.5		556 T	96	93	93
Storms 1969[a]	1	no or slight radiolucency	158 T	96	81	87
1950s or earlier						
Engstrom & Lundberg 1965	3.5-4	no radiolucency	129 T	n/a	n/a	76
Grossman *et al.* 1964	1-5	no symptoms & no radiolucency	432 T	98	62	90
Grahnen & Hansson 1961	4-5	no radiolucency, except around excess filler	205 R	75	73	74

a) results also include pulpectomies

TABLE 3. Reported success rates of root canal therapy according to tooth type and position

Study	Percent of cases reported to be a success (sample size)									
	Maxilla					Mandible				
	CI	LI	C	PM	M	CI	LI	C	PM	M
Sjogren *et al.* 1990	93 (40)	86 (70)	94 (54)	87 (170)	88 (125)	89 (56)		94 (49)	93 (138)	95 (147)
Pekruhn 1986	95 (416)			94 (191)		91 (137)			98 (181)	
Barbakow *et al.* 1980	94 (79)		93 (15)	92 (71)	94 (49)	80 (10)		80 (5)	90 (51)	63 (52)
Kerekes & Tronstad 1979	88 (41)	80 (41)	98 (42)	91 (95)	90 (93)	86 (14)		96 (27)	91 (91)	91 (67)
Jokinen *et al.* 1978	40 (202)	26 (191)	49 (150)	53 (322)	65 (517)	22 (50)	35 (51)	48 (93)	60 (230)	59 (653)
Storms 1969	85 (61)	87 (30)	86 (7)	90 (10)	75 (4)	57 (7)	71 (7)	86 (7)	100 (14)	100 (13)
MEAN	77	70	84	83	82	40	53	81	87	82
	82			84		76			87	
WEIGHTED MEAN	60	51	69	72	73	26	40	70	78	68
	72			75		70			74	

CI = central incisors
LI = lateral incisors
C = canines
PM = premolars
M = molars

TABLE 4. Reported success rates of root canal therapy on anterior and posterior teeth.

Study	Percent of cases reported to be a success (sample size)	
	Anterior Roots	Posterior Roots
Molven & Halse 1988	78 (308)	83 (218)
Shah 1988	89 (94)	89 (38)
Selden 1974	94 (1131)	95 (1167)
Engstrom & Lundberg 1965	92 (76)	84 (37)
Grahnen & Hansson 1961	73 (429)	88 (848)
MEAN	82	88
WEIGHTED MEAN	86	91
OVERALL MEAN (includes results from Table 3)	80	86
OVERALL WEIGHTED MEAN	79	81

TABLE 5a Retrospective studies of periapical surgery that included permanent posterior teeth - study design.

Study	Age of Patients	Period of Treatment	Patients Treated by	Follow-up Period (years)
All Teeth				
Frank *et al.* 1992[a]	??	1970s	Investigators	$\geq$ 10
Rapp *et al.* 1991	$\leq$90	1965-86+	Endodontic Specialists & Students	$\geq$ 0.5
Rud *et al.* 1991[a,b]	15-93	1980s	Investigators	0.5-1
Grung *et al.* 1990[a,c]	10-81	1980s	Principle Investigator	1
Hirsch *et al.* 1979	10-89	1969-73	University Clinic	0.5-3
Ericson *et al.* 1974	12-71	1958-72	University Clinic	0.5-12
Posterior Teeth				
Cheung & Lam 1993[a]	??	1980s	??	> 2
Friedman *et al.* 1991	13-73	1980-88	University Clinic	0.5-8
Rud *et al.* 1991[a,b]	??	1980s	Investigators	0.5-1
Ioannides & Borstlap 1983	17-52	1976-80	Hospital Clinic	0.5-5
Persson 1982	??	1974-79	??	$\geq$ 1
Altonen & Mattila 1976[a]	11-70	1960s	Principle Investigator	1-6
Ericson *et al.* 1974	12-71	1958-72	University Clinic	0.5-12

a) year of treatment not provided by authors but was estimated based upon year of publication and length of follow-up period
b) results from teeth restored with composite and from teeth restored with amalgam have been combined
c) see also Halse *et al*, 1991

TABLE 5b Retrospective studies of periapical surgery that included permanent posterior teeth - study results.

Study	Follow-up Period (years)	Number of Teeth at the Baseline Exam	Number of Teeth at the Follow-up Exam	Percent of Cases Where Periapical Healing is			Percent of Cases Extracted
				Complete	Incomplete or Uncertain	Unsatisfactory	
All Teeth							
Frank *et al.* 1992	≥ 10	??	104	58	not reported	42	not reported
Rapp *et al.* 1991	≥ 0.5	715	428	65	29	6	not reported
Rud *et al.* 1991[a]	0.5-1	??	776	66	26	8	not reported
Grung *et al.* 1990[b]	1	545	477	63	35	2	not reported
Hirsch *et al.* 1979	0.5-3	1345	572	47	48	5	0
Ericson *et al.* 1974	0.5-12	??	314	54	25	21	1
Posterior Teeth							
Cheung & Lam 1993	> 2	??	32	62	22	16	not reported
Friedman *et al.* 1991[c]	0.5-8	??	136	48	37	15	not reported
Rud *et al.* 1991[a]	0.5-1	??	578	69	24	7	not reported
Ioannides & Borstlap 1983	0.5-5	86	70	73	20	1	6
Persson 1982	≥ 1	??	26	73	15	12	not reported
Altonen & Mattila 1976	1-6	??	46	72	11	9	9
Ericson *et al.* 1974	0.5-12	??	159	52	20	27	not reported

a) results from teeth restored with composite and from teeth restored with amalgam have been combined
b) see also Halse *et al*, 1991
c) reported results with reference to roots rather than teeth

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