

Outcomes of Nonsurgical Retreatment and Endodontic Surgery: A Systematic Review

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Abstract

Introduction: The purpose of this systematic review was to compare the clinical and radiographic outcomes of nonsurgical retreatment with those of endodontic surgery to determine which modality offers more favorable outcomes. **Methods:** The study began with targeted electronic searches of MEDLINE, PubMed, and Cochrane databases, followed with exhaustive hand searching and citation mining for all articles reporting clinical and/or radiographic outcomes for at least a mean follow-up of 2 years for these procedures. Pooled and weighted success rates were determined from a meta-analysis of the data abstracted from the articles. **Results:** A significantly higher success rate was found for endodontic surgery at 2–4 years (77.8%) compared with nonsurgical retreatment for the same follow-up period (70.9%; $P < .05$). At 4–6 years, however, this relationship was reversed, with nonsurgical retreatment showing a higher success rate of 83.0% compared with 71.8% for endodontic surgery ($P < .05$). Insufficient numbers of articles were available to make comparisons after 6 years of follow-up period. Endodontic surgery studies showed a statistically significant decrease in success with each increasing follow-up interval ($P < .05$). The weighted success for 2–4 years was 77.8%, which declined at 4–6 years to 71.8% and further declined at 6+ years to 62.9% ($P < .05$). Conversely, the nonsurgical retreatment success rates demonstrated a statistically significant increase in weighted success from 2–4 years (70.9%) to 4–6 years (83.0%; $P < .05$). **Conclusions:** On the basis of these results it appears that endodontic surgery offers more favorable initial success, but nonsurgical retreatment offers a more favorable long-term outcome. (*J Endod* 2009;35:930–937)

Key Words

Endodontic surgery, nonsurgical retreatment, success, systematic review

The major goals of root canal treatment are to clean and shape the root canal system and seal it in 3 dimensions to prevent reinfection of the tooth (1, 2). Although initial root canal therapy has been shown to be a predictable procedure with a high degree of success (3–6), failures can occur after treatment. Recent publications reported failure rates of 14%–16% for initial root canal treatment (3, 7). Lack of healing is attributed to persistent intraradicular infection residing in previously uninstrumented canals, dentinal tubules, or in the complex irregularities of the root canal system (8–11). The extraradicular causes of endodontic failures include periapical actinomycosis (12), a foreign body reaction caused by extruded endodontic materials (13, 14), an accumulation of endogenous cholesterol crystals in the apical tissues (15), and an unresolved cystic lesion (16, 17).

Previously treated teeth with persistent periapical lesion(s) might be preserved with nonsurgical retreatment or endodontic surgery, assuming the tooth is restorable, periodontally sound, and the patient desires to retain the tooth. When a decision is made to preserve the tooth, the clinician and patient face the challenge of selecting the treatment with the most beneficial long-term outcome. Patients are entitled to the most current and accurate information regarding the prognosis of their treatment options, and it is the responsibility of an astute clinician to provide this information. Patients usually tend to choose treatment procedures consistent with the clinician's recommendation (18). However, it appears that the recommendations are often subjective and inconsistent, and there is a lack of consensus among dental professionals when making decisions related to retreatment or endodontic surgery (19–22).

Evidence-based dentistry recommends selection of alternate treatment options on the basis of the best available evidence (23). Paik et al (24) in 2004 identified clinical studies pertaining to the success and failure of nonsurgical endodontic retreatment and assigned a level of evidence to the pertinent articles. Mead et al (25) published a similar literature review in 2005 for clinical studies related to endodontic surgery. They reported that the endodontic literature lacks studies at the highest level of evidence and that the vast majority of literature are low-level case series. A number of expert opinion articles have been published discussing decision factors between nonsurgical endodontic retreatment and endodontic surgery (26–31). However, only 1 systematic review has been published that has compared the outcomes of these 2 procedures. Del Fabbro et al (32), as part of the Cochrane Collaboration in 2007, reviewed randomized controlled trials (RCTs) that directly compared nonsurgical endodontic retreatment with endodontic surgery. Their findings were based on only 3 articles with significant limitations. One of their articles was the study by Danin et al (33) in 1999, who reported short-term (1 year) postoperative follow-up data of only 38 patients. The small sample size and short follow-up time in this study are insufficient to adequately assess long-term success (34). Their other 2 articles were studies by Kvist and Reit (34) published in 1999 and 2000. Both studies reported on the same data set; the latter study reported

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postoperative discomfort only and did not address long-term outcomes data. On the basis of these 3 articles, Del Fabbro et al concluded that short-term healing rates might be higher in surgically treated cases. The authors recognized the lack of substantial evidence for making a sound decision regarding these alternative treatments.

The purpose of this systematic review was to compare the clinical and radiographic success rates of nonsurgical retreatment of root-filled teeth with those of teeth treated by endodontic surgery with a minimum mean follow-up of 2 years.

Methods

The protocol for this systematic review was developed following established guidelines (35). A well-defined review question was developed by using the Patient Population, Intervention, Comparison, and Outcome (PICO) framework.

Formulating the Review Question

The following PICO framework was developed for a systematic review of the existing literature regarding clinical and/or radiographic outcomes of nonsurgical retreatment and endodontic surgery. In patients with periodontally sound teeth that have had previous endodontic treatment but have persistent periapical pathosis and/or clinical symptoms, does nonsurgical retreatment, compared with endodontic surgery, result in better or worse clinical and/or radiographic outcomes?

Inclusion and Exclusion Criteria

Inclusion criteria for this review were articles from peer-reviewed journals published in English from January 1970–July 2008 that reported clinical and/or radiographic outcomes data for nonsurgical endodontic retreatment or endodontic surgery. Inclusion criteria also included studies that reported follow-up data for a minimum of 25 teeth and a minimum 2-year mean follow-up period. Exclusion criteria consisted of studies that did not meet the above inclusion criteria, studies that reported outcomes based on individual roots as opposed to whole teeth, studies that did not report clinical or radiographic outcomes, animal studies, or studies that reported histologic data only.

Search Methodology

Development of the search strategy began with the selection of 10 sentinel articles representative of the type of articles that the electronic search is intended to target for both the nonsurgical and endodontic surgery groups. These sentinel articles served to generate appropriate Medical Subject Headings and key words for the electronic searches. The search strategy was continuously enriched as additional terms were discovered during test searches. As a measure to confirm the validity of the search strategies, presence of the sentinel articles in the final search results was verified.

The initial electronic search was executed in MEDLINE via Ovid, and adaptations from the primary search were conducted in PubMed and Cochrane databases (electronic search strategy available on request). Because of limitations of the cataloging methods of electronic databases (36), the article list was enriched with other sources including expert recommendations and relevant chapters from 3 major endodontic texts: *Principles and Practice of Endodontics* (Torabinejad and Walton, 4th ed, 2008), *Pathways of the Pulp* (Cohen and Hargreaves, 9th ed, 2006), and *Endodontics* (Ingle, Bakland, and Baumgartner, 6th ed, 2008); every issue of the most recent 2 years of the following major endodontic journals: *International Endodontic Journal*; *Journal of Endodontics*; *Oral Surgery*, *Oral Medicine*, *Oral Pathology*, *Oral Radiology*, and *Endodontology*; and the reference

section from relevant articles for additional articles not identified by the previous methods.

Study Selection

The titles and abstracts of all articles identified from the electronic and hand searches were first screened to eliminate articles that clearly failed to meet the search criteria. Full-text copies of all remaining articles were printed and further examined to establish whether inclusion criteria were met. The investigators met and reviewed the remaining list of articles and developed consensus that the inclusion and exclusion criteria were respected and that key studies were not missed.

Rating the Quality of the Study

Study quality was assessed for each article by examining information such as the study type (such as prospective/retrospective and clinical trial), number of patients, number and type of procedures quantified (teeth/roots), study setting, experience of the providers, use of magnification (none, loupes, microscope), materials used, age range of patients, length of follow-up, and specific outcomes and data regarding the types of complications encountered during and after the procedures. This information was put into a 45-question data abstraction form, which was also used to assess internal validity by collecting information about elements of randomization, concealment of treatment allocation, blinding, and the handling of patient attrition.

On the basis of the abstracted information, an overall study rating score (37) was determined. A maximum score of 17 points was assigned to each article as follows: randomized clinical trial (4), non-randomized clinical trial (3), clinical trial with no controls or cohort (2), and case-control or case series (1). One additional point was granted for each of the following: total number of enrolled subjects stated, sample size predetermined, operator experience stated, evaluator different from the operator, treatment procedures completely described, demographic description included, complete description of subject loss, treatment complications described, measurements standardized, evaluation methods clearly described, intention to treat stated, and adequate description and appropriateness of statistical techniques and stratification.

Data Extraction

The investigators consolidated the data in the abstraction form, and a discussion was undertaken and consensus reached in the event of disagreements. When necessary, the reviewers recalculated success and failure rates when they were not directly provided in tables or in the text, or when only particular data subsets met the inclusion criteria. Data reported for roots could not be combined with data reported for teeth and were therefore excluded, because the outcomes of multi-rooted teeth are affected differently for these 2 units of measure.

To facilitate meta-analysis, the data were standardized according to a commonly applied classification system used to assess outcomes for nonsurgical retreatment and surgical endodontics derived from Rud et al (38): (1) Complete healing: This group includes cases that demonstrate resolution of apical radiolucencies, a re-formation of a normal periodontal ligament (PDL), and an absence of clinical signs and symptoms. (2) Incomplete healing: This group includes asymptomatic cases in which preoperative lesions have reduced in size or remained stable, with radiographic characteristics suggestive of scar tissue such as a lesion visibly separate or positioned asymmetrically around the apex with an angular connection to the periodontal space. (3) Uncertain healing: This group represents asymptomatic cases that demonstrate decreased size of original apical radiolucencies that remain more than twice the size of a normal PDL space.

TABLE 1. Evidence Table Summary for Periapical Surgery Evaluated by Teeth, with Pooled and Weighted Success and Functional Rates Accordingly

First author (reference)	Year	Time (y)	No.	Success no.	Success rate (%)	Wilson score interval		Quality score	
Harty (44)	1970	2–4	1016	914	89.96	87.97	91.65	5	
Ericson (45)	1974	2–4	314	168	53.50	48.01	58.91	2	
Finne (82)	1977	2–4	218	108	49.54	43.03	56.07	3.5	
Hirsch (61)	1979	2–4	572	417	72.90	69.13	76.37	6	
Mikkonen (83)	1983	2–4	174	99	56.90	49.55	63.95	5	
Skoglund (43)	1985	2–4	27	10	37.04	22.66	54.65	6	
Crosher (41)	1989	2–4	85	78	91.76	84.36	95.55	5	
Grung (49)	1990	2–4	477	416	87.21	83.94	89.89	6	
Molven (40)	1991	2–4	224	190	84.82	79.61	88.85	5	
Cheung (84)	1993	2–4	32	20	62.50	46.15	76.17	2	
Pantschev (85)	1994	2–4	103	56	54.37	44.94	63.49	6	
Lyons (63)	1996	2–4	97	86	88.66	81.11	93.26	3	
Chong (47)	2003	2–4	108	97	89.81	82.93	93.95	11	
Maddalona (86)	2003	2–4	120	111	92.50	86.61	95.75	6	
Penarrocha (87)	2007	2–4	333	239	71.77	66.74	76.30	5	
Kim (88)	2008	2–4	190	172	90.53	85.65	93.81	6	
Pooled success rate (95% CI)					75.6 (67.3–82.9)				
Weighted success rate (95% CI)					77.8 (76.3–79.2)				
Rud (80)	1972	4–6	1000	894	89.40	87.35	91.15	5	
Reit (89)	1986	4–6	35	33	94.29	82.93	96.89	5	
Jesslen (46)	1995	4–6	82	70	85.37	76.48	91.10	7	
Kvist (34)	1999	4–6	47	28	59.57	45.86	71.83	9	
Rahbaran (66)	2000	4–6	176	49	27.84	21.83	34.79	5	
Wesson (90)	2003	4–6	790	451	57.09	53.62	60.49	5.5	
Wang (62)	2004	4–6	90	70	77.78	68.40	84.88	12	
Pooled success rate (95% CI)					71.7 (51.7–88.0)				
Weighted success rate (95% CI)					71.8 (69.8–73.9)				
Frank (79)	1992	6+	104	60	57.69	48.26	66.57	4	
August (91)	1996	6+	39	35	89.74	77.48	94.88	5	
Wang (64)	2004	6+	194	117	60.31	53.36	66.86	3.5	
Pooled success rate (95% CI)					68.9 (52.1–83.5)				
Weighted success rate (95% CI)					62.9 (56.7–69.1)				
Combined Pooled success rate (95% CI)					73.8 (66.5–80.4)				
Combined Weighted success rate (95% CI)					75.0 (73.9–76.2)				

The associated 95% CIs were calculated by using DerSimonian Lair random effects model.

(4) Unsatisfactory healing (failures): This group represents cases in which the lesions remain unchanged or have enlarged compared with preoperative radiographs, or there is a presence of clinical signs or symptoms.

Not all articles reported outcomes in the above 4 categories. When uncertainty existed regarding which of the above 4 categories correlated with those reported in a given article, the data were assigned to the lower healing category. For this review, success was defined as teeth categorized as showing complete healing or incomplete healing, as is commonly reported (39–41). Failure was described as teeth showing uncertain healing or unsatisfactory healing.

Data Analysis

Weighted success rates, pooled success rates, and 95% confidence interval (CI) estimates of outcomes were generated in the meta-analysis from compiled data from the included studies by using the DerSimonian-Laird random effects pooling method. The pooling method is appropriate for comparison of heterogeneous data but less well-suited to large and disparate sample sizes. Conversely, weighting is unsuited to strongly heterogeneous data but is well-suited to large and disparate

sample sizes. The Wilson score method is a refinement of the simple asymptotic method designed to provide enhanced coverage and increased aberration avoidance (42).

Results

Description of the Existing Literature

The final list of articles generated after electronic and hand searching included 721 studies. After title and abstract screening, 88 of these articles were obtained for full text review. After full text review, 26 endodontic surgery and 8 nonsurgical retreatment articles remained for inclusion in this systematic review (Tables 1 and 2). The publication date ranged from 1998–2008 for nonsurgical retreatment literature and 1970–2008 for the endodontic surgery literature. A sum total of 8198 teeth were included in the meta-analysis. Sample sizes ranged from as few as 27 to as many as 1016 (43, 44). Study durations varied, but most studies reported mean outcomes data of less than 6 years. There were wide follow-up ranges within individual articles, with some studies reporting as wide as 6 months–12 years of follow-up information for the same data set (45). The large majority of studies included a combination of tooth types.

TABLE 2. Evidence Table Summary for Nonsurgical Retreatment Evaluated by Teeth, with Pooled and Weighted Success and Functional Rates Accordingly

First author (reference)	Year	Time (y)	No.	Success no.	Success rate (%)	Wilson score interval	Quality score
Gorni (60)	2004	2–4	452	311	68.81	64.42–72.89	5
Caliskan (56)	2005	2–4	86	53	61.63	51.29–70.97	10
Stoll (59)	2005	2–4	121	103	85.12	77.89–90.19	5
Pooled success rate (95% CI)					72.4 (59.4–83.6)		
Weighted success rate (95% CI)					70.9 (66.7–75.0)		
Sundqvist (57)	1998	4–6	50	37	74.00	60.99–83.59	6
Kvist (34)	1999	4–6	48	26	54.17	40.80–66.92	5
Farzaneh (53)	2004	4–6	99	83	83.84	75.59–89.56	8.5
Imura (58)	2007	4–6	624	536	85.90	82.97–88.39	7
de Chevigny (92)	2008	4–6	126	104	82.54	75.14–88.01	8.5
Pooled success rate (95% CI)					77.8 (68.7–85.7)		
Weighted success rate (95% CI)					83.0 (80.1–85.9)		
Combined Pooled success rate (95% CI)					75.6 (67.4–82.9)		
Weighted success rate (95% CI)					78.0 (75.6–80.4)		

The associated 95% CIs were calculated by using DerSimonian Lair random effects model.

Although some of the articles were well-detailed, many of the articles contained insufficient information to address many of the study quality assessment questions. The mean total quality score, out of a possible 17 points, was 7.1 ± 2.1 for nonsurgical retreatment studies and 5.5 ± 2.3 for endodontic surgery studies. Very few RCTs met the inclusion criteria, with only a single RCT in the nonsurgical retreatment group (34) and 3 RCTs in the endodontic surgery group (34, 46, 47). Overall, the included articles were dominated by less rigorous case-series analyses, which comprised 38% of the nonsurgical retreatment and 61% of the endodontic surgery articles. Only a single article included in this study made a direct comparison between the 2 treatment modalities (34). Generally when comparisons were made, they were between techniques or materials used.

The majority of the studies for both groups were conducted in a single setting, which most commonly was a teaching hospital or dental school setting. Studies were coded as being conducted in hospitals/dental schools (42%/65%), private practice (4%/25%), or other/unknown (23%/13%) for endodontic surgery and nonsurgical retreatment, respectively. Specialist involvement differed between treatment modalities. Studies were coded as describing care provided by students and general practitioners (15%/38%), specialists (50%/50%), or unstated (35%/13%) for endodontic surgery and nonsurgical retreatment, respectively. Whereas half of the nonsurgical retreatment studies reported an evaluator that was different than the operator, only 19% of endodontic surgery studies reported similar blinding.

The applied criteria for success and failure varied among the studies in both treatment modalities; thus its value is inherently limited. Measures used for assessment for endodontic surgery and nonsurgical retreatment articles, respectively, were radiographic only (27%/25%), radiographic and clinical assessment (62%/75%), or radiographic, clinical assessment, and questionnaire (8%/0%).

In general, the nonsurgical retreatment studies provided more completely detailed treatment methods when compared with endodontic surgery articles. Among the nonsurgical retreatment articles, removal of previous root filling materials was categorized as being performed with hand files (75%), rotary instrumentation (37.5%), heat (13%), or other (13%). Articles that reported the

use of solvents were coded as having used chloroform (63%), halothane (13%), or other (13%). The use of intracanal medication was reported in 75% of all articles, with Ca (OH)₂ being the predominant only medicament reported. Obturation materials used were gutta-percha (75%) or other/unstated (25%), with none reporting the use of silver points, pastes, or resins.

The status of the coronal restoration at follow-up examination was unstated in 77% of the articles. Use of magnification was also largely unstated, with 85% not describing the use of magnification aids, 9% describing the use of loupes, and only 6% indicating the use of a dental operating microscope. The majority of the articles in the endodontic surgery group failed to elaborate on flap design or hemostatics used during periapical surgery.

There were disparities among the endodontic surgery articles regarding techniques and materials used as well. Variations existed regarding whether root-end resections were performed and to what depth and bevel angle when they were done. Not all investigators reported performing root-end preparations, but among those who did, there was variability in the instruments used, the preparation depth, and the root-end filling materials used. Root-end preparations were performed with burs (29%), ultrasonics (18%), or was either not performed or not specified (53%). In descending order of frequency reported, root-end filling materials used included amalgam (73%), none (31%), "other" representing mostly resin or glass ionomer (31%), Super-EBA (19%), mineral trioxide aggregate (MTA) (12%), and intermediate restorative material (IRM) (8%). Several articles included multiple materials as part of the study.

Clinical and/or Radiographic Outcomes

Tables 1 and 2 report the pooled and weighted success rates for both the endodontic surgery and nonsurgical retreatment groups. Outcomes were combined across all follow-up periods and were also separated out into follow-up periods of 2–4, 4–6, and 6+ years recall periods. Separating the data into groups on the basis of recall periods allowed for examination of differences in weighted success rates both between and within the 2 treatment modalities over increasing follow-up time intervals.

When the data were combined across recall periods, no statistically significant difference was observed between the weighted success rates for endodontic surgery and nonsurgical retreatment. The overall weighted success rate for endodontic surgery was 75.0% (73.9%–76.2%), and for nonsurgical retreatment it was 78.0% (75.6%–80.4%) ($P < .05$).

Although the weighted success rates overall were not statistically significantly different between the 2 treatment modalities, interesting trends were observed when the data were separated according to increasing recall periods. When comparing endodontic surgery with nonsurgical retreatment, a significantly higher success rate was found for endodontic surgery at 2–4 years (77.8%) compared with nonsurgical retreatment for the same follow-up period (70.9%) ($P < .05$). At 4–6 years, however, this relationship was reversed, with nonsurgical retreatment showing a higher success rate of 83.0% compared with 71.8% for endodontic surgery ($P < .05$). Insufficient numbers of articles were available to make comparisons after 6 years of follow-up period.

Differences with respect to follow-up time within endodontic surgery studies showed a statistically significant decrease in success with each increasing follow-up interval for studies reporting on teeth ($P < .05$). The weighted success for 2–4 years was 77.8%, which declined at 4–6 years to 71.8% and further declined at 6+ years to 62.9%. With respect to the nonsurgical retreatment success rates, a statistically significant increase in weighted success was observed from 2–4 years (70.9%) to 4–6 years (83.0%) ($P < .05$). There were no studies included that reported 6+ years of follow-up for nonsurgical retreatment.

Discussion

The aim of this systematic review was to compare the success rates of nonsurgical endodontic retreatment with those of endodontic surgery to determine which treatment modality offers better clinical and radiographic outcomes according to existing literature. It is important to consider that only 1 article meeting criteria for inclusion made a direct comparison between endodontic surgery and nonsurgical retreatment (34), so the conclusions drawn in the present review are primarily the result of indirect comparisons. The most common reason for exclusion was failure to reach a 2-year minimum mean follow-up or insufficient detail in the article to confirm that this minimum follow-up time was met. A log of excluded articles and rationale for exclusion was maintained (available on request).

More than 3 times as many articles were included in this systematic review regarding endodontic surgery compared with nonsurgical retreatment. The meta-analysis was further constrained because data from articles that reported success rates for roots could not be combined with those that reported success on the basis of teeth because these measures could potentially yield markedly different results. To obtain only the most clinically relevant outcomes data, articles that measured outcomes on the basis of roots were not included in this systematic review.

Given these qualifications and all factors being equal, the evidence suggests that teeth retreated surgically have higher initial success than nonsurgical retreatment. However, a decline in success is observed for endodontic surgery with increasing time. Conversely, an increase in success is observed for nonsurgically retreated teeth leading to a higher rate of success compared with endodontic surgery at later follow-up periods. These findings are consistent with Kvist and Reit (34), who reported similar observations and offered an explanation of late failures in surgically treated teeth and slower healing dynamics in nonsurgically retreated teeth.

Very few RCTs (level of evidence 1 or 2) met the inclusion criteria, and most included articles that are lower-level case series (level of

evidence 4). These findings are consistent with those of Paik et al (24) as well as Mead et al (25). The overall quality scores out of a total possible score of 17 were 5.5 for surgical and 7.1 for nonsurgical studies, indicating a weakness in the endodontic literature for high level studies regarding endodontic surgery and nonsurgical retreatment.

For the purposes of this review, the healing categories complete healing and incomplete healing were combined and considered as success, which was a common approach among the included articles (48, 49). The rationale for this definition of success is derived from Rud et al (38), who demonstrated that the radiographic criteria for categorizing a tooth as exhibiting incomplete healing correlate histologically with an apical scar. This is also consistent with Molven et al (50), who reported that patients exhibiting radiographic findings suggestive of healing by scar tissue 1 year postoperatively remain predictably stable during recalls up to 12 years and should therefore be considered successful.

Teeth that were categorized as uncertain healing represented asymptomatic teeth demonstrating lesions that were reduced in size but not completely resolved. Outcomes such as these cannot be considered completely healed; however, the lack of symptoms and radiographic reduction of the lesion might represent a satisfactory situation for a patient and might not elicit further treatment recommendations from the treating dentists. Therefore, these teeth can be combined with the successful teeth and collectively considered functional, as described by previous authors (32, 51–53). On the basis of this definition, the combined weighted functional rate for nonsurgical retreatment is 78.8%, and for endodontic surgery the combined weighted functional rate is 84.4%. These percentages provide overall estimations for the likelihood that the given procedure will result in retention of a tooth that is providing function, is asymptomatic, and demonstrates a reduction in the preexisting pathosis.

The majority of studies reported presence of apical periodontitis as an indication for retreatment, but some articles included radiographic insufficiency of the previous root canal treatment alone as sufficient to justify retreatment. It has been well-documented in the literature that preoperative presence of a lesion adversely affects success (5, 52, 54–59). Among the nonsurgical retreatment articles included in this study that provide sufficient detail of preoperative periapical status, most reported a negative influence of apical periodontitis on the success of nonsurgical retreatment. These studies demonstrated a reduction in success of 13%–36% (5, 52, 54, 55, 57, 58, 60). The size of the apical lesion might also have a deleterious effect on outcomes for endodontic surgery, with larger lesions being related to less favorable healing. Among the surgical articles that stratified outcome data related to lesion size, a 5%–21% decrease in success was reported for teeth with greater than 5-mm-diameter lesions preoperatively, compared with those with lesions less than 5 mm in diameter (40, 45, 49, 61, 62). Although some individual articles reported significant differences relating to tooth type, tooth location (maxillary versus mandibular), and patient age, we did not observe clear patterns comparing the data from all the articles.

The quality of previous treatment was found to be an influential factor on the success of retreatment procedures. Pooled data from Phases 1–4 of the Toronto study relating to nonsurgical retreatment showed a 36% reduction in success correlating with previous root canal treatment that was assessed as adequate as judged by length and density of the obturation (52). The authors suggested that the etiology of failure in well-obtured teeth might be more likely related to extraradicular infection, cystic lesions, foreign body reactions, and undiagnosed infractions, conditions that might not respond favorably to retreatment. The authors also proposed that the microbial flora associated with the failure of inadequately treated teeth might be more susceptible to retreatment than the flora in well-treated teeth.

Preexisting procedural accidents also have a negative effect on healing. Gorni and Gagliani (60) examined the influence of alterations in the root canal morphology during previous treatment such as transportation and ledging. They found a 40% drop in nonsurgical retreatment success when there was a preexisting alteration in the morphology compared with teeth in which the canal morphology was respected. The presence of perforation results in a 31% decrease in success, as reported by de Chevigny et al (52).

Outcomes relating to the reoperation of teeth that had already been surgically treated previously showed reduced success rates compared with first-time surgery. Reported success rates were 5%–27% lower for re-surgery compared with first-time surgery (56, 62–65) according to most articles, with 1 article reporting 11% greater success for reoperated cases (66). A systematic review of re-surgery published in 2001 by Peterson and Gutmann (67) reported a failure rate of 38% for re-surgery, although no comparison was made to first-time surgery.

Studies that have made direct comparisons between the use of ultrasonic instruments and the use of burs for root-end preparation showed significantly better clinical outcomes when ultrasonics were used (68–72). However, less than 27% of the included articles reported the use of ultrasonics, whereas 38% reported the use of burs. More than one third of the articles either did not perform root-end cavity preparation or failed to report the technique used.

Studies that have made direct comparisons among root-end filling materials have consistently shown that modern materials offer more favorable clinical outcomes when compared with amalgam (39, 47). However, the large majority of articles in this review (73%) reported the use of amalgam as a root-end filling material. A meta-analysis of root-end filling materials by Fernandez-Yanez et al (73) reported that amalgam is associated with the lowest success rate compared with IRM, Super-EBA, and MTA. They also noted that MTA was the most biocompatible material studied and offers the best physical properties *in vitro*. Despite the predominance of evidence regarding the superior physical and biologic properties of MTA compared with alternate root-end filling materials (47, 73, 74), less than 12% of the qualifying articles for this review reported the use of MTA. This is likely a representation of the age of the literature and recent introduction of MTA as a root-end filling material.

Intraoperative complications such as separated instruments and perforation were associated with a 22% drop in success of nonsurgical retreatment, as reported by Imura et al (58) in 2007. Regarding surgical treatment, oroantral perforation into the maxillary sinus had no effect on prognosis (45). Compromise of the buccal plate, on the other hand, was associated with a 22%–30% decline in healing rate in apical surgeries (43, 61).

Another important consideration is the level of training and experience of the operators performing the procedures in the studies. Specialist involvement was reported for less than one third of the apical surgical articles and one fourth of the retreatment articles. General practitioners and students were the operators in half of the retreatment studies. Two thirds of the studies for both groups were conducted in hospital or school setting, with few being conducted in private practice. It has been suggested that procedural difficulty might be elevated in hospitals and teaching institutions as a result of the tertiary referral nature to this type of institution (66, 75).

The use of magnification during endodontic procedures, particularly the dental operating microscope (DOMS), provides enhanced visualization of the operating field, allowing for better discrimination of anatomic details, facilitates better control of instruments and placement of dental materials, and allows for improved detection and management of obstructions, anatomic variations, or fractures (11, 76, 77). Studies that have used the DOMS have shown high rates of

success for endodontic surgeries (47, 48, 78) and nonsurgical retreatment (52). Despite these benefits, the majority of articles did not report the use of magnification aids. Only 12% of the surgical articles and 8% of the retreatment articles in this study reported the use of a DOMS. The use of loupes was reported in only 6% of the surgical and 17% of the retreatment articles.

The articles that reported subgroups of teeth that were nonsurgically retreated before or in conjunction with endodontic surgery demonstrated 1%–25% higher success rates than when endodontic surgery was performed without prior nonsurgical retreatment (40, 44, 49, 62, 66).

A minimum of 2-year mean follow-up period was chosen as an inclusion criterion for this review. Length of follow-up time affects outcome, and 1-year follow-up periods might be insufficient to predict long-term healing, particularly for cases with preoperative lesions or when the healing is uncertain at 1 year (34, 79, 80). Frank et al (79) reported surgical outcomes from a population that showed healing at an early recall but found that 43% failed when the recall was extended beyond 10 years. Opposite findings were reported for nonsurgical retreatment by Fristad et al (81) in 2004, who found an improvement in healing at 20- to 27-year follow-up for teeth that demonstrated apical radiolucencies 10 years prior.

Method of evaluation can have a notable effect on reported outcomes. In comparison to studies that evaluate the individual roots, opportunity for failure can be tripled in multi-rooted teeth when the success of the tooth as a whole is assessed on the basis of the worst root. Several widely cited articles addressing outcomes of endodontic surgery and nonsurgical retreatment were excluded from this meta-analysis as a result of this criterion.

The data from this review showed a relationship between follow-up time interval and success. Although outcomes declined for surgically treated teeth with increasing observation time, a trend for improved outcome was observed for nonsurgical retreatment. It is important to consider that this systematic review included articles published up to 38 years before this meta-analysis. The field of endodontics is continually evolving as improvements in techniques and materials for endodontic procedures emerge, and a number of such advances have been made during the past 4 decades covered by this systematic review. Among these advances are the availability of enhanced magnification, ultrasonic instruments, and materials with improved physical and biologic properties. A large percentage of the studies in this review were conducted without the advantage of these recent advancements in technology. It is prudent to view the findings of the present review in light of this limitation, because modern endodontic practice is enriched with innovations that were not available when many of the included studies were conducted.

It is also important to note that the operators for some of the studies were students, and that only half of the articles reported specialist involvement. Furthermore, several of the studies included teeth with preoperative predictors of failure, including presence of perforations, apical lesions, advanced periodontal defects, or a history of prior retreatment procedures. Considering these limitations, it would stand to reason that operators with advanced training, by using judicious case selection and modern techniques and materials, could optimize the likelihood of success and expect outcomes more favorable than those presented in the current review. New studies that evaluate the outcomes of nonsurgical retreatment and apical surgery by using current techniques and materials are needed to determine whether the success of these procedures is improving with these advancements.

On the basis of the results of the present review it appears that endodontic surgery demonstrates more favorable initial healing, which declines with increasing recall periods. Conversely, the data suggest that

nonsurgical retreatment shows improved outcomes with increasing recall time. Because of the very limited amount of comparative evidence, there is an apparent need for high-quality long-term RCTs to further investigate the difference in outcomes between endodontic surgery and nonsurgical endodontic retreatment or a combination of these procedures.

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