Outcome of Endodontic Surgery: A Meta-analysis of the Literature—Part 1: Comparison of Traditional Root-end Surgery and Endodontic Microsurgery

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Abstract

Introduction: The aim of this study was to investigate the outcome of root-end surgery. The specific outcome of traditional root-end surgery (TRS) versus endodontic microsurgery (EMS) and the probability of success for comparison of the 2 techniques were determined by means of meta-analysis and systematic review of the literature. **Methods:** An intensive search of the literature was conducted to identify longitudinal studies evaluating the outcome of root-end surgery. Three electronic databases (Medline, Embase, and PubMed) were searched to identify human studies from 1966 to October 2009 in 5 different languages (English, French, German, Italian, and Spanish). Relevant articles and review papers were searched for cross-references. Five pertinent journals (*Journal of Endodontics, International Endodontic Journal, Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics, Journal of Oral and Maxillofacial Surgery, International Journal of Oral and Maxillofacial Surgery*) were individually searched back to 1975. Three independent reviewers (S.S., M.K., and F.S.) assessed the abstracts of all articles that were found according to predefined inclusion and exclusion criteria. Relevant articles were acquired in full-text form, and raw data were extracted independently by each reviewer. Qualifying papers were assigned to group TRS or group EMS. Weighted pooled success rates and relative risk assessment between TRS and EMS were calculated. A comparison between the groups was made by using a random effects model. **Results:** Ninety-eight articles were identified and obtained for final analysis. In total, 21 studies qualified (12 for TRS [n = 925] and 9 for EMS [n = 699]) according to the inclusion and exclusion criteria. Weighted pooled success rates calculated from extracted raw data showed 59% positive outcome for TRS (95% confidence interval, 0.55–0.6308) and 94% for EMS (95% confidence interval, 0.8889–0.9816). This difference was statistically significant ($P < .0005$). The relative risk ratio showed that the probability of success for EMS was 1.58 times the probability of success for TRS. **Conclusions:** The use of microsurgical techniques is superior in achieving predictably high success rates for root-end surgery when compared with traditional techniques *(J Endod 2010;36:1757–1765)*

Key Words

Amalgam, apicoectomy, endodontic microsurgery, IRM, meta-analysis, MTA, outcome, root-end surgery, success, SuperEBA, systematic review

Endodontic surgery is a dental procedure to treat apical periodontitis in cases that did not heal after nonsurgical retreatment or, in certain instances, primary root canal therapy (1). This might include situations with persistent or refractory intracanal infection after iatrogenic changes to the original canal anatomy (2) or microorganism in proximity of the constriction (3) and the apical foramen (4). Other reasons might be found in extraradicular infection, such as bacterial plaque on the apical root surface (5) or bacteria within the lesion itself (6–9).

Few dental techniques have been substantially transformed as has endodontic surgery. Various techniques were suggested to make the procedure easier to execute, safer for the patient, and more predictable (10). For many years, the state of the art was the traditional approach with surgical burs and amalgam for root-end filling (11–13). Modern techniques incorporate the use of ultrasonic tips and more biocompatible filling materials such as intermediate restorative material (IRM), SuperEBA, and mineral trioxide aggregate (MTA) (14). Endodontic microsurgery (EMS) is the most recent step in the evolution of periradicular surgery, applying not only modern ultrasonic preparation and filling materials but also incorporating microsurgical instruments, high-power magnification and illumination (15).

Although many studies have been published that advocate the use of modern approaches, the traditional techniques are still widely used in the oral surgery and maxillofacial surgery community, and the success rates of modern techniques are debated (16, 17). In 2008, a survey from the Netherlands reported the use of amalgam by oral surgeons as a root-end filling material at 35%, second only to IRM (18). MTA was only used in 2.6%, although it was recommended as the most biocompatible root-end filling material available to date (15, 19). Several reviews and meta-analyses were published on the outcome of endodontic surgery, but they failed to identify cumulative success rates for different techniques (10, 14, 20). One recent meta-analysis addressed the outcome of endodontic surgery with ultrasonic root-end preparation and modern filling materials, but it did not clearly distinguish between

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TABLE 1. Studies Included in the Meta-analysis

Study	Group	Language	Sample size	Follow-up (months)	Magnification	Root-end preparation
Finne et al, 1977 (89)	TRS	English	116	36	None	Bur
Hirsch et al, 1979 (99)	TRS	English	77	6–12	None	Bur
Malmström et al, 1982 (97)	TRS	English	78	6–12	None	Bur
Mikkonen et al, 1983 (87)	TRS	English	12	12–24	None	Bur
Forssell et al, 1988 (96)	TRS	English	44	12–48	None	Bur
Dorn and Gartner, 1990 (49)	TRS	English	294	6–120	None	Bur
Rapp et al, 1991 (45)	TRS	English	120	6	None	Bur
Zetterqvist et al, 1991 (47)	TRS	English	52	12	None	Bur
Pantschev et al, 1994 (61)	TRS	English	52	36	None	Bur
Jesslen et al, 1995 (42)	TRS	English	41	60	None	Bur
August, 1996 (40)	TRS	English	16	120–276	None	Bur
Schwartz-Arad et al, 2003 (58)	TRS	English	23	6–45	None	Bur
Rubinstein and Kim, 1999 (85)	EMS	English	94	14	Microscope	Ultrasonic
Von Arx et al, 2003 (35)	EMS	German	54	12	Endoscope	Ultrasonic
Chong et al, 2003 (36)	EMS	English	108	24	Microscope	Ultrasonic
Taschieri et al, 2005 (34)	EMS	English	28	12	Endoscope	Ultrasonic
Filippi et al, 2006 (31)	EMS	German	103	12	Endoscope	Ultrasonic
Taschieri et al, 2006 (32)	EMS	English	39	12	Endoscope	Ultrasonic
Taschieri et al, 2008 (26)	EMS	English	100	24	Endoscope /Microscope	Ultrasonic
Kim et al, 2008 (28)	EMS	English	148	12–60	Microscope	Ultrasonic
Christiansen et al, 2009 (70)	EMS	English	25	12	Microscope	Ultrasonic

studies that apply high-power magnification for the surgical procedure and those that did not (14).

To date, no study has established cumulative success rates for either the traditional or contemporary non-microsurgical or truly microsurgical techniques. To make an informed decision for clinical care, the highest evidence for any kind of treatment is desirable (21). If microsurgical endodontic surgery techniques do provide a better prognosis than traditional or non-microsurgical approaches, then the differences in outcome, as well as the probability for success, by comparing these techniques must be demonstrated to facilitate that decision for the better of the patient. Randomized controlled trials are seen as the gold standard but are either not available to support all medical or dental interventions (22) or might be deemed unethical because of current knowledge. Therefore, the best available evidence has to substitute in these situations (22). The aim of this systematic review was to provide the best available evidence in the absence of high level studies. A meticulous meta-analysis of the literature was undertaken for 5 languages to incorporate a large quantity of available information by raw data extraction and subsequent statistical analysis. The results of this investigation will be presented in 2 parts. The aims of the first part of this paper are to present and compare weighted pooled success rates and relative risk ratios for traditional root-end surgery (TRS) and EMS and to discuss the impact of these findings on the different specialties in the dental community. Part two will compare contemporary non-microsurgical techniques and EMS, the influence of the tooth type on the probability of success, and discuss this outcome in relation to the impact of microscopic dentistry in general and for the specialty of endodontics.

Materials and Methods

Before the literature search, a research question was defined according to the paradigm of evidence-based dentistry, following the Population, Intervention, Comparison, Outcome (PICO) format: "Teeth that have undergone a root-end surgery and root-end filling procedure (Population) by endodontic microsurgery (EMS) (Intervention) compared to traditional root-end surgery (TRS) (Comparison) have what expected probability of success according to longitudinal studies with strictly defined inclusion and exclusion criteria (Outcome)?"

Identification of Studies

Three electronic databases were searched for topic-related studies, regardless of the publication type. The term [(apicoectomy OR apicectomy OR root-end filling OR root-end surgery OR retrograde filling OR retro-grade surgery OR periapical surgery OR periradicular surgery OR surgical endodontic treatment OR apical microsurgery) AND (success OR treatment outcome)] was applied to search the Medline, Embase, and PubMed databases. Limits were studies on human subjects and publication in any of the 5 languages (English, French, German, Italian, and Spanish). The electronic database search covered the time frame from 1966 to the second week of October 2009. For the articles resulting from PubMed, the related articles search was conducted as well. Five relevant scientific journals (*Journal of Endodontics, International Endodontic Journal, Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics, Journal of Oral and Maxillofacial Surgery, International Journal of Oral and Maxillofacial Surgery*) were hand-searched back to 1975. All resulting titles and abstracts were individually screened by 3 independent reviewers (S.S., M.K., and F.S.) for relevance of the topic: if they were definitely to be excluded, included, or a conclusion was not possible from the title or even the abstract. In situations where no agreement was reached by independent abstract review, a final agreement was reached by discussion until a consensus was reached. Full articles were obtained by electronic or traditional search methods for all review articles, relevant titles, and all articles where no conclusion was possible from reading the abstract. The references of all these articles were searched for cross-references that had not been found before, and the additional abstracts were subjected to the same reviewing process. Three experts in the field were contacted to reveal possible gray literature in form of ongoing studies or consensus reports by the major endodontic societies.

Inclusion and Exclusion Criteria

The selection of studies was based on the following inclusion criteria:

1. Clinical study on root-end surgery.
2. Sample size given.

Root-end filling	Success	Failure	Reported success rate	Weight	Study design
Amalgam	67	49	57.8%	478.49	Randomized clinical trial
Amalgam	48	29	62.3%	327.84	Retrospective case study
Amalgam	42	36	53.9%	313.81	Retrospective case study
Amalgam	9	3	75.0%	64.00	Retrospective case study
Amalgam	31	13	70.5%	478.49	Retrospective case study
Amalgam	171	123	58.2%	1208.50	Retrospective case study
Amalgam	85	35	70.8%	580.45	Retrospective case study
Amalgam	28	24	53.9%	209.21	Randomized clinical trial
Amalgam	27	25	51.9%	208.30	Prospective study with concurrent controls
Amalgam	20	21	48.8%	164.09	Randomized clinical trial
Amalgam	10	6	62.5%	68.27	Retrospective case study
Amalgam	10	13	43.5%	208.30	Retrospective case study
Super EBA	91	3	96.8%	3034.61	Prospective case study
Super EBA	48	6	88.9%	547.23	Prospective study with concurrent controls
MTA/IRM	97	11	89.8%	1179.09	Randomized clinical trial
Super EBA	26	2	92.9%	424.51	Prospective case study
Super EBA	96	7	93.2%	1625.22	Prospective case study
Super EBA	37	2	94.9%	805.80	Randomized clinical trial
Super EBA	91	9	91.0%	1221.00	Randomized clinical trial
Super EBA/MTA/IRM	141	7	95.2%	3238.80	Prospective study with concurrent controls
MTA	25	0	100.0%	252.53	Randomized clinical trial

3. A minimum follow-up period of 6 months.
4. Success and failure were evaluated by using the radiographic parameters and clinical assessment of Rud et al (23) or Molven et al (24). Radiographically, success was defined as either complete or incomplete healing (scar tissue formation) and clinically by the absence of pain, swelling, percussion sensitivity, or sinus tracts. Failure included uncertain healing (reduction or same lesion size) or unsatisfactory healing (increase in lesion size) as determined on the radiograph. Clinical failure was defined as the persistent presence of any of the symptoms mentioned above.
5. Success and failure were evaluated per tooth.
6. The overall success rate was given for the specific technique or could be calculated from the raw data.
7. The method used in the study strictly followed either the specific techniques for traditional root-end surgery (group TRS) or for endodontic microsurgery (group EMS). In group TRS, root-end preparation was made by using burs, root-end fillings with amalgam, and 0× to 4× magnification. In group EMS, ultrasonic root-end preparation and root-end filling were IRM, SuperEBA, or MTA, and high-power illumination and magnification were 10× and higher.
8. Study limited to humans.
9. Publication in English, French, German, Italian, or Spanish.

All studies that did not meet the inclusion criteria or demonstrated any of the following exclusion criteria were excluded:

1. Study not evaluating the outcome of root-end surgery.
2. No sample size given.
3. Root-end surgery performed on lesions more than 10 mm in diameter.
4. Teeth presenting with apico-marginal defects or teeth with periodontal disease (periodontal pockets and/or mobility).
5. Use of guided tissue regeneration.
6. Surgery after previous endodontic surgery (re-surgery cases), root resections and amputations, cases presenting with root fractures or perforations.
7. Less than 6 months of follow-up.
8. Outcome not evaluated according to the success and failure criteria defined above.
9. Success rate was not given, only reported for roots, data extraction or success rate calculation for TRS or EMS from raw data not possible.
10. Root-end surgery performed with a technique or combination of techniques that does not fit the specific criteria defined for TRS or EMS.
11. *In vitro* or animal study, case report, review article, or opinion paper.
12. Studies based on a population that was part of an earlier publication.
13. Publication in any other language than those mentioned in the inclusion criteria.

Data Extraction

The electronic database literature search resulted in a total of 1152 citations, of which 1020 could be excluded as not related to dentistry or the research subject by review of the title. Of the remaining 132 studies, 38 were eliminated because the abstract review revealed no relevance to the topic, 16 publications because they were review articles, and additional 14 articles because it was obvious from the abstract that although related to the topic, the article did not comply with study characteristics pertinent to the research interest of this investigation. Sixty-four articles were obtained for full-text review on the basis of the electronic database search. Cross-references of these articles as well as the 16 review articles and the hand-search of the 5 relevant journals revealed 34 additional publications that were relevant, resulting in a total of 98 studies that were obtained as full-text copies. Of these, 82 articles were published in English, 13 in German, 2 in Spanish, 1 in Italian, and none in French. Expert consultation revealed 1 consensus report on periradicular surgery in preparation for a major endodontic society. However, all articles included in this report had already been found in the literature search, so there was no further consideration to avoid duplicate data. Disagreements on study inclusion or exclusion were resolved by discussion until an agreement between the 3 reviewers was reached. Cohen kappa statistical analysis was obtained for this process at 2 stages: stage 1 after the abstract review to determine whether a publication had to be obtained as a full-text copy and stage 2 at the final decision for inclusion into either group TRS or EMS or

TABLE 2. Excluded Studies with Detailed Reasons for Exclusion from the Meta-analysis

Study	Language	Exclusion Criteria
Saunders, 2008 (27)	English	8
de Lange et al, 2007 (29)	English	10
von Arx et al, 2007 (30)	English	6
Taschieri et al, 2005 (34)	English	10
Wesson and Gale, 2003 (17)	English	4, 10
Maddalone and Gagliani, 2003 (37)	English	10
Oginni and Olusile, 2002 (13)	English	2,9
von Arx et al, 2001 (38)	English	10
Testori et al, 1999 (39)	English	2,9,10
Sumi et al, 1996 (41)	English	8,10
Reinhart et al, 1995 (43)	German	9,10
Cheung and Lam, 1993 (44)	English	9,10
Lustmann et al, 1991 (46)	English	2,9
Grung et al, 1990 (48)	English	4,10
Berrone and Aimetti, 1989 (50)	Italian	9
Palattella et al, 1987 (51)	Italian	1,11
Ioannides and Borstlap, 1983 (52)	English	2,9
Harty et al, 1970 (12)	English	2,8,9
Gagliani et al, 2005 (53)	English	10
Wang et al, 2004 (54)	English	4,8,9,10
von Arx and Kurt, 1999 (55)	English	8,10
Pecora and Adreana, 1993 (56)	English	7,10
Ilgenstein and Jäger, 2006 (57)	French, German	1,11
Danin et al, 1996 (59)	English	10
Rud et al, 1996 (60)	English	10
Frank et al, 1992 (62)	English	8.9
Wang et al, 2004 (63)	English	4,9,10
Halse et al, 1991 (64)	English	9,10
Rahbaran et al, 2001 (16)	English	9,10
Molven et al, 1996 (65)	English	1
Carrillo et al, 2008 (66)	English	2,3,9,10
Kvist and Reit, 1999 (67)	English	9,10
Allen et al, 1989 (68)	English	9,10
Beckett and Briggs, 1995 (69)	English	11
Peñarrocha et al, 2001 (70)	English	10
Martí et al, 2008 (72)	English	10
Friedman et al, 1991 (73)	English	9
Lyons et al, 1995 (74)	English	1,2,8
Shearer and McManners, 2008 (75)	English	10
Lindeboom et al, 2005 (76)	English	10
Reit and Hirsch, 1986 (77)	English	10
Rubinstein and Kim, 2002 (78)	English	12
Molven et al, 1991 (79)	English	9,10
Vallecillo Capilla et al, 2002 (80)	Spanish, English	10
Zuolo et al, 2000 (81)	English	10
Wälivaara et al, 2007 (82)	English	10
Luebke, 1974 (83)	English	11
Andreasen et al, 1972 (84)	English	8
Burke, 1979 (88)	English	11
Jansson et al, 1997 (90)	English	10
Block et al, 1976 (91)	English	9
von Arx et al, 2007 (92)	English	10
Kimura, 1982 (93)	English	10
Tay et al, 1978 (94)	English	12
Edmunds, 1979 (95)	English	1,11
Altonen and Mattila, 1976 (98)	English	9
Hirsch et al, 1979 (99)	English	12
Bader and Lejeune, 1998 (100)	English	6,10
Nordenram and Svärdstrom, 1970 (101)	English	10
Block et al, 1979 (102)	English	8
Andreasen and Rud, 1972 (103)	English	8
Arwill et al, 1974 (104)	English	8
Herzog et al, 1995 (105)	German	8,10
el-Swiah and Walker, 1996 (106)	English	1,11
Bumberger-Niesslbeck et al, 1987 (107)	German	1
Becker et al, 1987 (108)	German	1
Kopp et al, 1987 (109)	German	1
Lindemann et al, 1987 (110)	German	1
Cordes et al, 1987 (111)	German	10
Geiger and Peuten, 1987 (112)	German	1
Mohr et al, 1987 (113)	German	10
Haas et al, 1995 (114)	German	1
Ortega-Sánchez et al, 2009 (115)	English	10
Peñarrocha et al, 2007 (116)	English	10
Marti-Bowen et al, 2005 (117)	Spanish, English	10
García et al, 2008 (118)	English	10
Peñarrocha et al, 2008 (119)	English	10

exclusion. The articles that were finally selected were categorized into 6 categories following a protocol described by Iqbal and Kim (25): best, better, good, average, fair, and unknown. The category "unknown" did not fit in any of the other 5 categories or where the attempt of data extraction did not retrieve any information. The 5 previous categories were described as best (randomized controlled trial, double-blind), better (prospective study with concurrent controls), good (prospective study with historical controls), average (prospective case study), or fair (retrospective case study). The following raw data were extracted from the studies, if available: sample size of teeth, roots, molars, premolars, and anteriors; follow-up period; use of inclusion and exclusion criteria for surgery; type of magnification; type of root-end preparation; root-end filling material; statistical methods; treatment success in teeth, roots, molars, premolars, and anteriors; reported success rate; success criteria; number of cases with complete, incomplete, uncertain healing, and failure. The data were transferred to custom-designed data acquisition spreadsheets and subjected to statistical analysis.

Statistical Analysis

SPSS v15.0 (SPSS Inc, Chicago, IL), Minitab v15.0 (Minitab Inc, State College, PA), and Excel 2007 (Microsoft Corporation, Redmond, WA) were used for all descriptive and inferential analyses. The power of the study was estimated by using STATA v10 (StataCorp LP, College Station, TX).

Results

Of the 98 (12, 13, 16, 17, 26–119) citations found after abstract review, a total of 21 studies were included in the meta-analysis and are listed in Table 1. Regarding the quality of the articles, there were 7 randomized controlled trials (best) (26, 32, 36, 42, 47, 64, 89), three prospective studies with concurrent controls (better) (28, 35, 61), three prospective case studies (average) (31, 34, 85), and 8 retrospective case studies (fair) (40, 45, 49, 58, 87, 96, 97, 99) (Table 1). At stage 1, the kappa value between the 3 reviewers for keeping or rejecting articles was 97.0%. For the 4 articles where no initial agreement was reached, the question of inclusion or exclusion was resolved by discussion until a final common agreement was found. The detailed reasons for the exclusion of the 77 articles that were not considered after full article review were recorded and are listed in Table 2. Two articles (78, 94) were excluded as duplicates because the original data presented in these studies had already been analyzed in an earlier publication. The initial inter-reviewer agreement for the final selection of the 21 articles in groups TRS and EMS, stage 2,

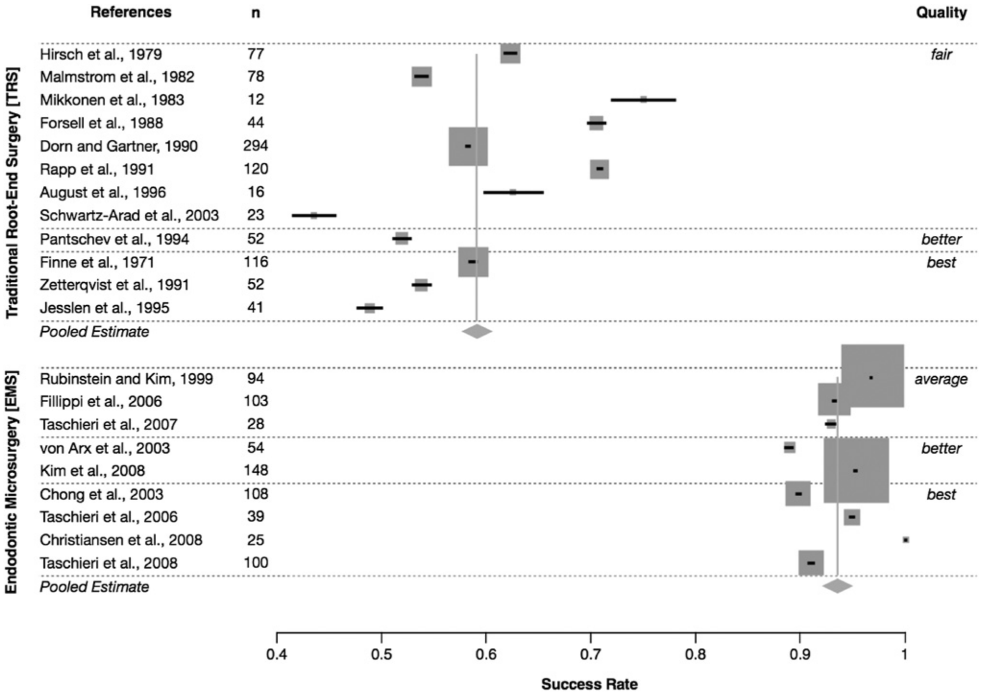

Figure 1. Weighted pooled success rates and individual study weights for groups TRS and EMS.

was 95.9%. After discussion and joint agreement, 12 articles qualified for group TRS and 9 studies for group EMS.

Success rates, after a minimum follow-up period of 6 months for TRS and EMS, were derived from the dataset and are shown individually in Table 1. Weights for the individual studies were calculated as the inverse variance. The TRS group included 12 studies (combined sample size, n = 925) with a weighted pooled success rate of 59% (59.04%; 95% confidence interval [CI], 0.55–0.6308). The EMS group included 9 studies (n = 699). One study (70) presented a 100% success rate; therefore, the standard error was zero, and the weight calculation by the inverse variance left the weight for this study undefined. A remedial solution was used, adjusting the success rate for the study as 0.99 and computing the inverse variance from the adjustment following the example of a publication with a similar situation (120). The final weighted pooled success rate for the EMS group was 94% (93.52%; 95% CI, 0.8889–0.9816). The individual weights and the pooled success rates are shown in forest plots (Fig. 1).

A homogeneity analysis was performed to assess the assumption that all of the effect sizes were estimating the same population mean. Within-groups homogeneity was achieved, [Q (19) = 21.23, P = .3243], with variance comprised from group TRS [Q (11) = 19.49, P = 0.053] and group EMS [Q (8) = 1.74, P = .988]. Between-groups homogeneity was not achieved [Q (1) = 12.081, $P < .0005$]. To adjust for this, a random effects model was used.

The standardized mean difference between the 2 groups was calculated by using probits of individual group success probabilities to obtain a z-score for group comparison. Differences between the groups were statistically significant (z = 31.84, standard error = 0.0232, $P < .0005$).

A 2 × 2 contingency table was used to derive a relative risk ratio and odds ratio for the 2 groups. The relative risk ratio indicated that the probability of success for group EMS was 1.58 times the probability of success for group TRS. The odds ratio indicated that group EMS had 10.01 times the odds of success as did group EMS (odds ratio, 9.54; 95% CI, 6.90–13.19). Chi-square analysis on the frequencies of success and failures between the 2 groups also indicated a significant difference (χ^2 (1) = 239.03, $P < .0005$).

The power of the investigation was 1.0, on the basis of the 95% level of significance.

Discussion

Part one of this investigation determined and compared the outcome of TRS versus EMS and evaluated the probability of success in a comparison of the 2 techniques. These 2 techniques for root-end surgery differ significantly in the means to achieve the goal of periapical healing. Significant differences in TRS and EMS include the access armamentarium (standard size surgical bur versus bone cutting bur or piezo tip), size of the osteotomy (large versus small), use of instruments (large regular versus small microinstruments), bevel angle (acute versus shallow), root-end preparation (bur versus ultrasonic tip), direction of preparation (off-angle versus aligned), the root-end filling material (amalgam versus better biocompatible cements), and the possible identification of microfractures and additional canals under the high-power magnification of a microscope or endoscope (15). Although these differences are known to a large percentage of the endodontic community, there is still considerable use of the TRS techniques by many dental practitioners.

One example can be seen in the oral surgery community, where on the one hand the placement of endosseous implants was very successfully integrated, yet root-end surgery is not carried out by using the technical advancements in dentistry at the same frequency as it is done in endodontics (18). In the authors' opinion, increasingly specializing fields of dentistry disallow individual practitioners to see the broader spectrum of dentistry and to acknowledge progress and advancements in other specialties. Not only was a significantly different outcome for TRS and EMS never presented as a direct comparison, but also many review articles on root-end surgery present a combined outcome, regardless of whether it resulted from historic or contemporary techniques (10, 121, 122). Other articles disregarded traditional techniques, which lead to a much better understanding of the success probability of root-end surgery in modern endodontics (14). Nevertheless, if the differences between techniques are not identified, for both aforementioned scenarios, the variability in outcome does not become evident at a high level of evidence. As a result, traditional techniques are still used, and because there is a significantly lesser outcome of TRS, as presented here, this might lead to the perception that root-end surgery per se does not work if only these techniques are used in dental practice. This might add also to the variability of treatment approaches between different specialties. It has been shown that treatment choices vary greatly depending on specialty, even for identical situations. This has been demonstrated for primary endodontic treatment (123) as well as for retreatment scenarios (unpublished data, Setzer et al). For both scenario groups, decision making for teeth with need for primary endodontic treatment or retreatment, specialists who are primary implant providers favored tooth extraction and subsequent placement of a dental implant over endodontic therapy, with the opposite outcome for endodontists and a more even distribution among general practitioners.

The results of this investigation might also shed a different light on the treatment decision for nonsurgical versus surgical retreatment. From an evidence-based point of view, 2 different approaches exist to this particular question. Prospective randomized clinical trials and their systematic reviews are seen as the highest level of evidence (124). One Cochrane review exists that investigates this treatment decision question (125). In lieu of a sufficient number of high level studies, this article attempts to draw a conclusion from 3 randomized clinical trials, of which 2 share the same study population, and report only additional findings based on the same investigation in the consecutive publication. Moreover, the 2 studies that were incorporated and yield extractable data do not use any means of magnification, use burs for the root-end preparation and glass ionomer cement or heated gutta-percha as root-end filling materials, as acknowledged by the authors. As a result, a purportedly highest evidence level article de facto draws conclusions from 2 study populations that were treated with moderately accepted surgical techniques and an overall sample size of 163 at an estimated difference in probability of success between surgical and nonsurgical retreatment of approximately 6%. According to biomedical statistical literature, accepting a two-tailed type I error of 0.05%, 398 total samples would be necessary for an expected outcome difference of 10% between 2 interventions and 1370 for 5% difference to achieve a power of 80% (126). For a power of 90%, the required numbers would amount to total sample sizes of 532 (10%) and 1832 (5%), respectively (126). This is a well-known problem inherent in many dental studies. Thus, for a prospective randomized clinical trial with a statistically significant meaning of the outcome comparison of TRS versus EMS, a large population would be needed. It is the authors' perspective that given the historical success rates of individual studies for TRS and EMS and the fact that mercury-containing amalgam would have to be implanted into connective tissue, it seems unlikely that a prospective randomized clinical trial comparing these techniques would receive approval of the institutional review board of any major institution.

An alternative approach suggests the incorporation of validated raw data, extracted from high, mid, and lower level studies. In lieu of high level studies with sufficient sample sizes or prognostic multicenter studies, Ng et al (22) proposed a triangulated approach consisting of the reported findings from the incorporated studies, weighted pooled success rates, and the effects of prognostic factors together with individual study characteristics.

In this context, this meta-analysis tried to access and incorporate as much available data as possible. Hence, the literature search was extended to manual search of not only primarily general dentistry or endodontic publications but also oral and maxillofacial surgery journals to identify studies that were generated by the specialty of oral surgery. Moreover, the language criteria were broadened to include studies that might have been published in the major languages of continental European countries and South America and yielded appropriate data, especially enlarging the sample size in the microsurgical group. In the authors' opinion, extending the language criteria to Chinese, Japanese, and Portuguese might be advisable for future undertakings in this direction, considering the volume of dental literature published in these languages. This was, however, not possible for this study, because we were limiting the search to languages where we could exclude the possibility of data misinterpretation by translation deficits.

In contrast to other studies, this investigation looked into the outcome differences of commonly combined techniques for root-end surgery rather than single factors. Von Arx et al (127) published a detailed meta-analysis of individual parameters influencing the outcome of root-end surgery, including root-end filling materials, gender, or tooth type. For the purpose of this study, 2 additional commonly investigated groups had been identified from the literature besides TRS and EMS. These were non-microscopic or non-endoscopic techniques, yet with ultrasonic root-end preparation and amalgam or IRM, SuperEBA, MTA root-end filling. For the prospective non-microscopic or non-endoscopic amalgam group, the available sample size after article review and application of the inclusion and exclusion criteria turned out to be too small for acceptable statistical power and was therefore turned down for evaluation. The last group, which we termed contemporary root-end surgery (CRS), is subject to investigation in the second part of this meta-analysis, highlighting differences in outcome between root-end surgeries carried out with or without high-power magnification and illumination, yet with the same basic modern techniques.

As a result, the weighted pooled success rates for TRS were comparatively lower than for EMS. To reach a sufficient data size, the minimum follow-up period for this comparison had to be set at 6 months. One of the criticisms for this investigation is that all studies in the EMS group have a minimum follow-up period of at least 12 months, and this might lead to unfair bias in the results. There were, however, no studies qualified for group EMS that had less than 12-month follow-up. At a minimum of 12-month follow-up period, not enough studies would have qualified for group TRS to allow this comparison at all. Six months of additional healing might not have decreased lesion sizes in the TRS group compared with the EMS group. It has been shown that cases that were determined as success or failure after 6–12 months demonstrate the same healing pattern after longer follow-up periods (23, 42, 128). Teeth with uncertain healing patterns after a recall period of 1 year will likely result in complete healing within 4 years (20). In addition, reported success rates for studies in the TRS group with a follow-up period of more than 6 months were not considerably higher than at 6-month follow-up. It appears more likely that disadvantages of amalgam, including creep or corrosion, are responsible for failures. Gaps of up to 150 μm between the root-end cavity margin and amalgam are reported in the literature (129). The resulting overall difference between the weighted pooled success rates of TRS versus EMS was by far too large to see a possibility for a significant change in the comparison outcome with an extended healing period.

As for the results for EMS, the cumulative success rate of 93.52% lies exactly in the range with the data presented by Ng et al (22) for primary endodontic treatment without periapical lesion, with a weighted pooled positive outcome of 93.5% after a minimum of 6-month follow-up and survival rates for restored endodontically treated teeth after primary treatment (94%) and restored single unit implants (95%) as reported by Iqbal and Kim (25). The overall reported weighted pooled success rate in a similar investigation on the outcome of secondary root canal treatment was given as 77.2%. Considering the fact that most surgical approaches are carried out on cases with periapical lesions, the cumulative success as presented in the aforementioned study was only 65.7% with the presence of periapical pathology, yet 93.5% without. One should never, however, use these success rates as a justification to use the surgical approach immediately. First, although comparable in regard to strict healing criteria for both surgical and nonsurgical endodontic treatment, the types of healing are different. Whereas with a surgical intervention, the healing pattern is that of an excisional wound, the progress after nonsurgical therapy is indirect after eradicating the infectious source from the root canal system. Therefore, slightly different success criteria for surgical and nonsurgical endodontic treatment have to be used and substitute to bridge a comparison. The application of common success criteria, as attempted in previous reviews by using the periapical index, might thus not be appropriate (54). Second, different clinical situations might necessitate only either the nonsurgical or surgical treatment approach (1). Influencing factors are the possibility to reenter the original canal morphology (2), access to the root canal system, and the dental history of the teeth involved.

Last, it has to be stressed that for endodontic surgery, a successful outcome in terms of healing of the existing periapical pathology, together with a good long-term prognosis of the tooth, depends on a sound case selection. In general, most endodontically treated teeth are rarely extracted because of endodontic reasons (8.6%), but primarily as a result of restorative (32.0%) or periodontal (59.4%) failures (130). Kim and Kratchman (15) suggested a surgical classification A–F for proper case selection. Classes A–C are characterized by being primarily endodontic lesions; classes D–F describe cases with associated periodontal involvement. In a comparison of surgical outcome of these classes, Kim et al (28) found a successful outcome of 95.2% for cases classified as A–C but only 77.5% for D–F, the cases with endodontic-periodontal combined lesions. Studies taken into the groups TRS or EMS in this investigation had to follow case selection criteria, as outlined in the study exclusion criteria above, to avoid any unwanted bias related to failures not originating from an endodontic cause.

In conclusion, on the basis of the meta-analysis presented here, the probability of success for EMS proved significantly greater than the probability of success for TRS. This demonstrates the evolution of periapical surgery and what can be achieved with contemporary techniques including enhanced magnification and visualization. Part two of this study addresses the question whether microsurgical techniques are always needed in endodontic surgery or might not be necessary for certain tooth types. From the results of this investigation the use of TRS techniques should not any longer be considered state of the art.

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