# Outcome of Endodontic Surgery: A Meta-analysis of the Literature—Part 2: Comparison of Endodontic Microsurgical Techniques with and without the Use of Higher Magnification

*Frank C. Setzer, DMD, PhD, MS, Meetu R. Kohli, BDS, DMD, Sweta B. Shah, BDS, DMD, Bekir Karabucak, DMD, MS, and Syngcuk Kim, DDS, PhD*

## Abstract

**Introduction:** The aim of this study was to investigate the outcome of root-end surgery. It identifies the effect of the surgical operating microscope or the endoscope on the prognosis of endodontic surgery. The specific outcomes of contemporary root-end surgery techniques with microinstruments but only loupes or no visualization aids (contemporary root-end surgery [CRS]) were compared with endodontic microsurgery using the same instruments and materials but with high-power magnification as provided by the surgical operating microscope or the endoscope (endodontic microsurgery [EMS]). The probabilities of success for a comparison of the 2 techniques were determined by means of a meta-analysis and systematic review of the literature. The influence of the tooth type on the outcome was investigated. **Methods:** A comprehensive literature search for longitudinal studies on the outcome of root-end surgery was conducted. Three electronic databases (ie, Medline, Embase, and PubMed) were searched to identify human studies from 1966 up to October 2009 in 5 different languages (ie, English, French, German, Italian, and Spanish). Review articles and relevant articles were searched for cross-references. In addition, 5 dental and medical journals (ie, *Journal of Endodontics*, *International Endodontic Journal*, *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics*, *Journal of Oral and Maxillofacial Surgery*, and *International Journal of Oral and Maxillofacial Surgery*) dating back to 1975 were hand searched. Following predefined inclusion and exclusion criteria, all articles were screened by 3 independent reviewers (S.B.S., M.R.K., and F.C.S.). Relevant articles were obtained in full-text form, and raw data were extracted independently by each reviewer. After agreement among the reviewers, articles that qualified were assigned to group CRS. Articles belonging to group EMS had already been obtained for part 1 of this meta-analysis. Weighted pooled success rates and a relative risk assessment between CRS and EMS overall as well as for molars, premolars, and anteriors were calculated. A random-effects model was used for a comparison between the groups. **Results:** One hundred one articles were identified and obtained for final analysis. In total, 14 studies qualified according to the inclusion and exclusion criteria, 2 being represented in both groups (7 for CRS [n = 610] and 9 for EMS [n = 699]). Weighted pooled success rates calculated from extracted raw data showed an 88% positive outcome for CRS (95% confidence interval, 0.8455–0.9164) and 94% for EMS (95% confidence interval, 0.8889–0.9816). This difference was statistically significant ($P < .0005$). Relative risk ratio analysis showed that the probability of success for EMS was 1.07 times the probability of success for CRS. Seven studies provided information on the individual tooth type (4 for CRS [n = 457] and 3 for EMS [n = 222]). The difference in probability of success between the groups was statistically significant for molars (n = 193, $P = .011$). No significant difference was found for the premolar or anterior group (premolar [n = 169], $P = .404$; anterior [n = 277], $P = .715$). **Conclusions:** The probability for success for EMS proved to be significantly greater than the probability for success for CRS, providing best available evidence on the influence of high-power magnification rendered by the dental operating microscope or the endoscope. Large-scale randomized clinical trials for statistically valid conclusions for current endodontic questions are needed to make informed decisions for clinical practice. *(J Endod 2012;38:1–10)*

## Key Words

Apicoectomy, dental operating microscope, endodontic microsurgery, endoscope, IRM, loupes, meta-analysis, microscope, mineral trioxide aggregate, outcome, root-end surgery, success, SuperEBA, systematic review

The goal of endodontic therapy is the prevention or elimination of apical periodontitis. Root-end surgery may be indicated in cases with persistent or refractory periradicular pathosis that does not heal after nonsurgical retreatment (1). This can be caused by both intraradicular or extraradicular infections that cannot be addressed by an orthograde treatment approach.

The first part of this meta-analysis dealt with the question how the outcome of traditionally applied surgical techniques in endodontics compared with endodontic

From the Department of Endodontics, School of Dental Medicine, University of Pennsylvania, Philadelphia, Pennsylvania.

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Address requests for reprints to Dr Frank C. Setzer, Instructor, Department of Endodontics, School of Dental Medicine, University of Pennsylvania, 240 South 40th Street, Philadelphia, PA 19104. E-mail address: fsetzer@dental.upenn.edu

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microsurgery (2). For the purpose of the investigation, 2 groups had been defined. In brief, studies had been grouped either as traditional root-end surgery (TRS) or endodontic microsurgery (EMS). Studies in group TRS used conventional burs and amalgam root-end fillings without the application of magnification devices, whereas studies in group EMS used the operating microscope or an endoscope with high-power magnification together with microsurgical instruments, ultrasonic root-end preparation, and more biocompatible filling materials such as IRM, SuperEBA, or MTA. The weighted pooled success rates calculated from the raw data of 12 studies in TRS and 9 studies in EMS showed a 59% positive outcome for TRS (95% confidence interval [CI], 0.55–0.6308) and 94% for EMS (95% CI, 0.8889–0.9816) based on Rud's and Molven's success criteria for periapical surgery. This difference was statistically significant ($P < .0005$). A relative risk analysis showed that the probability of success for EMS was 1.58 times the probability of success for TRS. From this study, it was concluded that the use of microsurgical techniques is superior in achieving predictably high success rates for root-end surgery than with traditional techniques as defined earlier.

The protocol for endodontic microsurgery suggests to use mid-range magnification (8–14×) for the majority of the surgical procedures, including hemostasis, the removal of granulation tissue, the detection of root tips, apicoectomy, root-end preparation, and root-end filling (3). High magnification (14–26×) should be used for the inspection and documentation of the resected root surface, the root-end cavity, and the root-end filling to allow for the observation of fine anatomic details, such as accessory canals, isthmi, fins, microfractures, or lateral canals (3). Tsesis et al (4) suggested that the identification and treatment of microscopically small anatomic details should result in a more successful outcome. Besides the studies that strictly use microsurgical techniques, including high-power magnification (EMS), there are other investigations on the outcome of endodontic surgery that also apply microsurgical instruments, ultrasonic root-end preparation, and the same biocompatible filling materials but do not use any or only low-range magnification. This raises the question whether the use of high-power magnification is critical as a single factor if all other microsurgical techniques are applied, but only loupes or no magnification device are used.

Based on the previous systematic review and meta-analysis of the literature that had been performed to compare cumulative success rates and relative risk ratios for TRS and EMS, this second part of the investigation presents the comparison of contemporary root-end surgery techniques with only loupes or no magnification devices (contemporary root-end surgery [CRS]) with the previously reported data on endodontic microsurgery using high-power magnification provided by the dental microscope or the endoscope (EMS) to assess the impact of the microscope or endoscope on the prognosis of endodontic surgery by the means of cumulative success rates and relative risk ratios. Studies in CRS were defined as the identical techniques as EMS with the exception of the use of magnifications 10× and above. It also investigates the influence of the tooth type on the probability of success.

## Materials and Methods

According to the PICO (Population, Intervention, Comparison, Outcome) format, the following research question had been formulated before the search for matching publications: Teeth that have undergone a root-end surgery and root-end filling procedure (population) by EMS (intervention) compared with CRS (comparison) have what expected probability of success according to longitudinal studies with strictly defined inclusion and exclusion criteria (outcome)?"

### Identification of Studies

A detailed description of the literature search that identified relevant articles can be found in part 1 of this investigation (2). Briefly, 3 electronic databases (Medline, Embase, and PubMed) were searched for related articles, regardless of the publication type, using the term {(apicoectomy OR apicectomy OR root-end filling OR root-end surgery OR retro-grade filling OR retro-grade surgery OR periapical surgery OR periradicular surgery OR surgical endodontic treatment OR apical microsurgery) AND (success OR treatment outcome)}. The search was limited to studies on humans in either English, French, German, Italian, or Spanish from 1966 to the second week of October 2009. In addition, 5 relevant journals (*Journal of Endodontics*, *International Endodontic Journal*, *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics*, *Journal of Oral and Maxillofacial Surgery*, and *International Journal of Oral and Maxillofacial Surgery*) dating back to 1975 were hand searched. Review articles and matching publications were searched for cross-references. Three independent reviewers (S.B.S., M.R.K., and F.C.S.) screened the relevant articles, checked for inclusion or exclusion, and extracted the raw data for analysis. Cohen kappa statistics were applied to check interreviewer agreement. Full articles were obtained either electronically or as paper versions. Gray literature was identified by consulting 3 experts on the subject matter for publications or consensus reports in the making. Within the timeframe between the submission of parts 1 and 2 of this meta-analysis, the endodontic literature was carefully reviewed for recent articles on the subject matter.

### Inclusion and Exclusion Criteria

Studies were selected based on the following inclusion criteria:

1. Clinical study was on root-end surgery.
2. Sample size was given.
3. There was a minimum follow-up period of 12 months.
4. Success and failure were evaluated using Rud's (5) or Molven's (6) radiographic parameters and clinical assessment. 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 complete failure (increase in lesion size) as determined from the radiograph. Clinical failure was defined as the presence of any of the symptoms mentioned previously.
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 followed strictly either the specific techniques for CRS or EMS as follows: CRS: modern microsurgical instruments and filling materials (microinstruments; ultrasonic root-end preparation; and root-end filling with IRM, SuperEba, or MTA) but with magnification ≤10× (loupes or no magnification devices) and EMS: the same microsurgical instruments and filling materials but with the surgical operating microscope or endoscope allowing magnification >10×.
8. Study was limited to humans.
9. Publication was in English, French, German, Italian, or Spanish.

Studies were excluded if the inclusion criteria were not met or showed any of the following exclusion criteria:

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

## Data Extraction

In total, the database search resulted in 1,152 citations. Of these, 1,020 were excluded as irrelevant to the subject title review. An additional 68 studies were eliminated from the remaining 132 studies after abstract review. The remaining 64 articles were obtained for full-text analysis based on the electronic database search. Cross-referencing of these publications and 16 review articles as well as the hand search of the 5 relevant journals revealed additional 34 publications of relevance. Between the publication of part 1 of the meta-analysis and the preparation of the manuscript for part 2, 3 additional publications on the outcome of endodontic surgery were identified (7–9). In total, 101 studies were obtained as full-text copies. The language distribution of these articles is listed in part 1 of this investigation. The articles were subjected to a 6-category quality assessment detailed in the first part of this study. For all relevant studies, the following data were extracted from the articles for statistical analysis: sample size in teeth, roots, molars, premolars, and anteriors; follow-up period; the use of inclusion and exclusion criteria for surgery; the type of magnification; the type of root-end preparation; root-end filling material; statistical methods; success in teeth, roots, molars, premolars, and anteriors; the reported success rate; success criteria; and the number of cases with complete, incomplete, uncertain healing, and failure.

## 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 analyses was estimated using STATA v10 (StataCorp LP, College Station, TX). For the comparison between the weighted pooled success rates of CRS and EMS, including the overall comparison and the 3 subcategories (ie, molars, premolars, and anteriors), the following statistical analyses were performed: a homogeneity analysis to assess the assumption that all of the effect sizes were estimating the same population mean. Standardized mean differences between CRS and EMS were calculated using probits of individual group success probabilities to obtain a z score for group comparison overall and for all 3 other categories; $2 \times 2$ contingency tables were used to derive relative risk ratios and odds ratios. Chi-square analysis on the frequencies of success and failures was used to investigate statistically significant differences between CRS and EMS for the overall comparison, premolars, and anteriors. The Fisher exact test was used in lieu of chi-square analysis for the molar subcategory because 1 cell in the contingency table had an expected value of <5.

# Results

## Inclusion and Exclusion of Studies

In total, 1,189 citations were reviewed, 1,088 eliminated, and 101 reviewed. Of the 101 citations obtained after abstract and full-text review, a total of 14 records were included in this second part of the meta-analysis (10–23). Data from 2 articles were used for CRS as well as EMS (12, 15), bringing the total number to 7 datasets for CRS (10–16) and 9 datasets for EMS (12, 15, 17–23). There were 6 randomized controlled trials (best) (13, 15, 16, 18, 21, 23), 2 prospective studies with concurrent controls (better) (12, 22), and 6 prospective case studies (average) (10, 11, 14, 17, 19, 20) included into the analysis (Table 1).

The initial kappa value between the 3 reviewers at stage 1 for keeping or rejecting articles was 97.0%. Discussion among the 3 reviewers resolved the question of inclusion or exclusion for the 4 articles when no agreement had been reached. The detailed reasons for the exclusion of the 87 articles that were not taken into consideration after full-article review were noted (17, 24–106) (Table 2). Two articles (17, 77) were excluded because the original data from these publications had been already analyzed in 2 earlier studies. None of the 3 articles identified after conduction of the full-scale systematic review could be included in the meta-analysis for CRS or EMS. One article investigated the differences in outcome between endodontic microsurgery with MTA and with Retroplast (7). Within the MTA group, which was complying with the inclusion criteria for microsurgical techniques, primary surgeries as well as resurgeries were included and could not be separated for raw data extraction. Another article (8) looked into the effect of nonsurgical retreatment before periapical surgery. The success and failure evaluation in the cases that underwent surgery for this study combined the results for incomplete healing (classified as success in this meta-analysis) with uncertain healing (classified as failure) and could not be separated for data extraction from an eligible treatment group. The third study (9) only investigated the outcome of resurgery cases. The initial interreviewer agreement for the selection of the 14 articles in groups CRS and EMS at stage 2 was 94.2%. The issues were discussed until a joint agreement was reached.

## Comparison of Contemporary Root-end Surgery with Only Loupes or No Visualization Aids (CRS) versus Endodontic Microsurgery with High-power Magnification (EMS)

**Overall Comparison.** Success rates at the 12-month examination for CRS and EMS were derived from the dataset. The 7 studies (n = 610) included in CRS resulted in a weighted pooled success rate of 88.09% (95% CI, 0.8455–0.9164). As reported in part 1 of the meta-analysis, the 9 studies included in EMS yielded a weighted pooled success rate of 93.52% (95% CI, 0.8889–0.9816) (Fig. 1) (2). The detailed remedial solution for the incorporation of Christiansen et al (23), which had a 100% success rate and thus presented with a statistical problem as the inverse variance was undefined, was described in part 1 of this investigation. Briefly, the remedial solution adjusted the

**TABLE 1.** Studies Included in the Meta-analysis

| Study | Group | Language | Sample size | Follow-up (months) | Magnification | Root-end preparation | Root-end filling | Success | Failure | Reported success rate (%) | Weight | Study design |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zuolo et al, 2000 (10) | CRS | English | 102 | 12–48 | None | Ultrasonic | IRM | 93 | 9 | 91.2 | 1270.933 | Prospective case study |
| Maddalone et al, 2003 (11) | CRS | English | 120 | 36 | Loupes 4.0× | Ultrasonic | Super EBA | 111 | 9 | 92.5 | 1729.7298 | Prospective case study |
| von Arxet al, 2003 (12) | CRS | English | 61 | 12 | None | Ultrasonic | Super EBA | 46 | 15 | 75.4 | 328.8693 | Prospective study with concurrent controls |
| Lindeboom et al, 2005 (13) | CRS | English | 100 | 12 | Loupes 3.5× | Ultrasonic | MTA/IRM | 89 | 11 | 89.0 | 1021.4505 | Randomized clinical trial |
| Taschlerl et al, 2005 (14) | CRS | English | 46 | 12 | Loupes 4.3× | Ultrasonic | Super EBA | 42 | 4 | 91.3 | 579.1190 | Prospective case study |
| Taschieri et al, 2006 (15) | CRS | English | 32 | 12 | Loupes 4.3× | Ultrasonic | Super EBA | 29 | 3 | 90.6 | 375.7457 | Randomized clinical trial |
| Lange et al, 2003 (16) | CRS | English | 149 | 14 | None | Ultrasonic | IRM | 120 | 29 | 80.5 | 716.4323 | Randomized clinical trial |
| Rubinstein and Kim, 1999 (17) | EMS | English | 94 | 14 | Microscope | Ultrasonic | Super EBA | 91 | 3 | 96.8 | 3034.6074 | Prospective case study |
| von Arx et al, 2003 (12) | EMS | German | 54 | 12 | Endoscope | Ultrasonic | Super EBA | 48 | 6 | 88.9 | 547.2289 | Prospective study with concurrent controls |
| Chong et al, 2003(18) | EMS | English | 108 | 24 | Microscope | Ultrasonic | MTA/IRM | 97 | 11 | 89.8 | 1179.0908 | Randomized clinical trial |
| Taschieri et al, 2005 (19) | EMS | English | 28 | 12 | Endoscope | Ultrasonic | Super EBA | 26 | 2 | 92.9 | 424.5051 | Prospective case study |
| Filippi et al, 2006 (20) | EMS | German | 103 | 12 | Endoscope | Ultrasonic | Super EBA | 96 | 7 | 93.2 | 1625.2209 | Prospective case study |
| Taschieri et al, 2006(15) | EMS | English | 39 | 12 | Endoscope | Ultrasonic | Super EBA | 37 | 2 | 94.9 | 805.8018 | Randomized clinical trial |
| Taschieri et al, 2008 (21) | EMS | English | 100 | 24 | Endoscope/ microscope | Ultrasonic | Super EBA | 91 | 9 | 91.0 | 1221.0012 | Randomized clinical trial |
| Kim et al, 2008 (22) | EMS | English | 148 | 12–60 | Microscope | Ultrasonic | Super EBA/ MTA/IRM | 141 | 7 | 95.2 | 3238.7955 | Prospective study with concurrent controls |
| Christiansen et al, 2009 (23) | EMS | English | 25 | 12 | Microscope | Ultrasonic | MTA | 25 | 0 | 100.0 | 252.5253 | Randomized clinical trial |

MTA, mineral trioxide aggregate.

individual success rates to 0.99 and computed the inverse variance from the adjustment (107).

Homogeneity analysis showed that within-group homogeneity was achieved ($Q[14] = 15.68$, $P = .333$) with variance comprised from EMS ($Q[8] = 6.57$, $P = .584$) and CRS ($Q[6] = 9.11$ , $P = .167$). Between the groups, homogeneity was not achieved ($Q[1] = 8.03$, $P = .005$). Therefore, a random-effects model was used for adjustment. The standardized mean difference between the CRS and EMS was statistically significant (z = 53.60, standard error = .0171, $P < .0005$). The relative risk ratio indicated that the probability of success for EMS was 1.07 times the probability of success for CRS. The odds ratio indicated that EMS had 2.09 times the odds of success as did CRS (odds ratio = 2.09, 95% CI, 1.43–3.04). Chi-square analysis on the frequencies of success and failures between the 2 groups indicated a significant difference ($\chi^2_1 = 15.19$, $P < .0005$). The statistical power of the overall investigation was estimated at 0.922 based on the 95% level of significance.

**Molars.** A total of 6 records were included in the meta-analysis of molar treatment success (Table 3). Success rates at the 12-month examination for CRS and EMS were derived from the dataset. CRS included 4 studies (n = 146) with a weighted pooled success rate of 90.24% (95% CI, 0.8340–09709). EMS included 2 studies (n = 47) with a weighted pooled success rate of 97.95% (95% CI, 0.8958–1.0). Each of the 2 study groups had 1 study that included a success rate of 100% (EMS: Taschieri, 2008 [21]; CRS: Taschieri, 2005 [14]). The standard error for these 2 individual studies was zero. Weights were calculated as the inverse variance; therefore, weights for these studies were undefined. The situation was adjusted analog to the solution that had been made to include Christiansen et al (23) in the overall comparison (107).

Within-group homogeneity was achieved ($Q[4] = 6.69$, $P = .153$) with variance comprised from EMS ($Q[1] = .07$, $P = .795$) and CRS ($Q[3] = 6.62$ , $P = .085$). Between-group homogeneity was also achieved ($Q[1] = 1.95$, $P = .162$). The standardized mean difference between the groups was statistically significant (z = 29.74, standard error = .0313, $P < .0005$). The relative risk ratio indicated that the probability of success for EMS was 1.09 times the probability of success for CRS. The odds ratio indicated that EMS had 9.04 times the odds of success as CRS (odds ratio = 9.04, 95% CI, 1.19–68.83). The Fisher exact test showed that the differences in success and failure between the 2 groups were statistically significant (z = −3.85, $P = .011$). The statistical power was estimated at 0.497 based on the 95% level of significance.

**Premolars.** A total of 7 records were included in the meta-analysis of premolar treatment success, and success rates were derived from the dataset (Table 3). CRS included 4 studies (n = 110) with a weighted pooled success rate of 90.37% (95% CI, 0.8488–0.9586) and EMS 3 studies (n = 59) with a weighted pooled success rate of 94.6% (95% CI, 0.8878–1.0).

Within-group homogeneity was validated ($Q[5] = 6.5$, $P = .256$) with variance comprised from EMS ($Q[2] = 2.23$, $P = .329$) and CRS ($Q[3] = 4.32$, $P = .229$). Between-group homogeneity was not achieved ($Q[1] = 1.07$, $P = .301$), and a random-effects model was used to assess the data. The standardized mean difference between the groups was statistically significant (z = 36.93, standard error = .0248, $P < .0005$). The relative risk ratio indicated that the probability of success for EMS was 1.05 times the probability of success for CRS. The odds ratio indicated that EMS had 1.57 times the odds as did CRS of success (1.57, 95% CI, 0.538–4.611). However, the CI for the odds ratio included zero; therefore, it was determined that the odds ratio result was not significant. Chi-square analysis on the

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

| Study | Language | Exclusion criteria |
|---|---|---|
| Saunders, 2008 (24) | English | 7, 8 |
| Finne et al, 1979 (25) | English | 10 |
| von Arx et al, 2007 (26) | English | 6 |
| Hirsch et al, 1979 (27) | English | 10 |
| Wesson and Gale, 2003 (28) | English | 4, 10 |
| Malmström et al, 1983 (29) | English | 10 |
| Oginni and Olusile, 2002 (30) | English | 2, 9 |
| von Arx et al, 2001 (31) | English | 8 |
| Testori et al, 1999 (32) | English | 2, 9 |
| Sumi et al, 1996 (33) | English | 7, 8, 10 |
| Reinhart et al, 1995 (34) | German | 9, 10 |
| Cheung and Lam, 1993 (35) | English | 9, 10 |
| Lustmann et al, 1991 (36) | English | 2, 7, 9 |
| Grung et al, 1990 (37) | English | 4, 10 |
| Berrone and Aimetti, 1989 (38) | Italian | 9, 10 |
| Palattella et al, 1987 (39) | Italian | 1, 11 |
| Ioannides and Borstlap, 1983 (40) | English | 2, 7, 9, 10 |
| Harty et al, 1970 (41) | English | 2, 8–10 |
| Gagliani et al, 2005 (42) | English | 8 |
| Wang et al, 2004 (43) | English | 4, 8–10 |
| von Arx and Kurt, 1999 (44) | English | 8 |
| Pecora and Adreana, 1993 (45) | English | 7, 10 |
| Ilgenstein and Jäger, 2006 (46) | French, German | 1, 7, 11 |
| Danin et al, 1996 (47) | English | 10 |
| Rud et al, 1996 (48) | English | 10 |
| Frank et al, 1992 (49) | English | 8, 9 |
| Wang et al, 2004 (50) | English | 4, 9, 10 |
| Halse et al, 1991 (51) | English | 9, 10 |
| Rahbaran et al, 2001 (52) | English | 9, 10 |
| Molven et al, 1996 (53) | English | 1, 12 |
| Mikkonen et al, 1983 (54) | English | 10 |
| Carrillo et al, 2008 (55) | English | 2, 3, 9, 10 |
| Kvist and Reit, 1999 (56) | English | 9, 10 |
| Allen et al, 1989 (57) | English | 7, 9, 10 |
| Beckett and Briggs, 1995 (58) | English | 11 |
| Peñarrocha et al, 2001 (59) | English | 10 |
| Marti et al, 2008 (60) | English | 10 |
| Friedman et al, 1991 (61) | English | 7, 9, 10 |
| Lyons et al, 1995 (62) | English | 1, 2, 8, 10 |
| Shearer and McManners, 2008 (63) | English | 7, 8 |
| Forssell et al, 1988 (64) | English | 7, 10 |
| Reit and Hirsch, 1986 (65) | English | 10 |
| Rubinstein and Kim, 2002 (17) | English | 12 |
| Molven et al, 1991 (66) | English | 9, 10 |
| Vallecillo Capilla et al, 2002 (67) | Spanish, English | 7, 8 |
| Dorn and Gartner, 1990 (68) | English | 7, 10 |
| Wälivaara et al, 2007 (69) | English | 3, 4 |
| Luebke, 1974 (70) | English | 11 |
| Andreasen et al, 1972 (71) | English | 8 |
| Burke, 1979 (72) | English | 11 |
| Jansson et al, 1997 (73) | English | 7, 8, 10 |
| Block et al, 1976 (74) | English | 7–10 |
| von Arx et al, 2007 (75) | English | 10 |
| Kimura, 1982 (76) | English | 11 |
| Tay et al, 1978 (77) | English | 10, 12 |
| Edmunds, 1979 (78) | English | 1, 11 |
| Altonen and Mattila, 1976 (79) | English | 9, 10 |
| Waikakul and Punwutikorn, 1991 (80) | English | 7, 8, 10 |
| Bader and Lejeune, 1998 (81) | English | 6 |
| Nordenram and Svärdstrom, 1970 (82) | English | 10 |
| Block et al, 1979 (83) | English | 8, 10 |
| Andreasen and Rud, 1972 (84) | English | 8, 10 |
| Arwill et al, 1974 (85) | English | 8 |
| Herzog et al, 1995 (86) | German | 8, 10 |
| el-Swiah and Walker, 1996 (87) | English | 1, 11 |

(*Continued*)

**TABLE 2.** (*Continued*)

| Study | Language | Exclusion criteria |
|---|---|---|
| Bumberger-Niesslbeck et al, 1987 (88) | German | 1 |
| Becker et al, 1987 (89) | German | 1 |
| Kopp et al, 1987 (90) | German | 1 |
| Lindemann et al, 1987 (91) | German | 1 |
| Cordes et al, 1987 (92) | German | 10 |
| Geiger and Peuten, 1987 (93) | German | 1 |
| Mohr et al, 1987 (94) | German | 10 |
| Haas et al, 1995 (95) | German | 1 |
| Ortega-Sánchez et al, 2009 (96) | English | 8, 10 |
| Penarrocha et al, 2007 (97) | English | 8, 10 |
| Marti-Bowen et al, 2005 (98) | Spanish, English | 8, 10 |
| Garcia et al, 2008 (99) | English | 8, 10 |
| Penarrocha et al, 2008 (100) | English | 10 |
| Rapp et al, 1991 (101) | English | 7, 10 |
| Zetterqvist et al, 1991 (102) | English | 10 |
| Pantschev et al, 1994 (103) | English | 10 |
| Jesslen et al, 1995 (104) | English | 10 |
| August, 1996 (105) | English | 10 |
| Schwartz-Arad et al, 2003 (106) | English | 7, 10 |
| von Arx et al, 2010 (7) | English | 6, 9 |
| Taschieri et al, 2010 (8) | English | 9 |
| Song et al, (9) | English | 6 |

frequencies of success and failures between the 2 groups were not significant ($\chi^2_1$ = 0.70, $P$ = .404). The statistical power was estimated to be at 0.08 based on the 95% level of significance.

**Anteriors.** A total of 7 records were included in the meta-analysis of anterior treatment success (Table 3). Success rates were derived from the dataset, with CRS including 4 studies (n = 161) with a weighted pooled success rate of 92.41% (95% CI, 0.8833–0.9649) and EMS including 3 studies (n = 116) with a weighted pooled success rate of 94.52% (95% CI, 0.9041–0.9863).

Within-group homogeneity was achieved ($Q[5]$ = 2.79, $P$ = .732) with variance comprised from EMS ($Q[2]$ = 1.884, $P$ = .390) and CRS ($Q[3]$ = 0.907, $P$ = .824). Between-group homogeneity was also achieved ($Q[1]$ = 0.509, $P$ = .476). The standardized mean difference was statistically significant (z = 63.3, standard error =.0148, $P$ < .0005). The relative risk ratio indicated that the probability of success for EMS was 1.01 times the probability of success for CRS. The odds ratio showed that EMS had 1.19 times the odds of success as CRS (odds ratio = 1.19, 95% CI, 0.48–2.96). Chi-square analysis showed no statistically significant difference between EMS and CRS ($\chi^2_1$ = 0.13, $P$ = .715). The statistical power was estimated to be at 0.062 based on the 95% level of significance.

## Discussion

Over the past decade, endodontic surgery has evolved into endodontic microsurgery by the introduction of the surgical microscope (45, 108–110) and/or the endoscope (111, 112). Although the use of the surgical microscope in general dentistry is still debated, its use for nonsurgical and surgical endodontics has become a routine procedure for endodontists since the 1990s and has been made a requirement for postgraduate education in the United States in 1998 (113). Based on a survey among active members of the American Association of Endodontists in the United States, 52% of the endodontists who had been surveyed had had access to a dental operating microscope in 1999 (114). In 2008, a web-based survey of these active members revealed that access and use of the microscope

**TABLE 3.** Studies Included in the Meta-analysis of Molar, Premolar, and Anterior Groups

| Study | Group | Sample size | Molars n/success | Molars success (%) | Premolars n/success | Premolars success (%) | Anteriors n/success | Anteriors success (%) |
|---|---|---|---|---|---|---|---|---|
| de Lange et al, 2003 (16) | CRS | 149 | 73/56 | 76.7* | 48/39 | 81.3* | 28/25 | 89.3* |
| Taschieri et al, 2005 (14) | CRS | 46 | 6/6 | 100.0* | 8/7 | 87.5* | 32/29 | 90.6* |
| Maddalone et al, 2003 (11) | CRS | 120 | 28/27 | 96.4* | 30/27 | 90.0* | 62/57 | 91.9* |
| Zuolo et al, 2000 (10) | CRS | 102 | 39/33 | 84.6* | 24/23 | 95.8* | 39/37 | 94.9* |
| | Total | 417 | 146/122 | 90.24* | 110/96 | 90.37* | 161/148 | 92.41* |
| Taschieri et al, 2008 (21) | EMS | 100 | 16/16 | 100.0* | 22/19 | 86.4* | 62/56 | 90.3* |
| Taschieri et al, 2005 (14) | EMS | 28 | 0/0 | NA | 6/5 | 83.3* | 22/21 | 95.5* |
| Rubinstein and Kim, 1999 (17) | EMS | 94 | 31/30 | 96.8* | 31/30 | 96.8* | 32/31 | 96.7* |
| | Total | 222 | 47/46 | 97.95* | 59/54 | 94.60* | 116/108 | 94.52* |

NA, not applicable.

*Weighted pooled success rate.

had increased to 90% (115). No data exist on the general distribution of the endoscope in dentistry or the specialty of endodontics.

High magnification allows for better identification of isthmi or accessory canals (116, 117) and enhances the visualization as well as improves the management of anatomic aberrations, prior iatrogenic complications, fractures, or canal obstructions, such as separated instruments or calcifications (3). It was recommended to help with the identification of dentinal cracks when the resected root surface is stained by dyes such as methyleneblue (3). It has been shown in *in vitro* studies that the accuracy of identifying dentinal cracks on resected root surfaces was not significantly different between unaided observation and high magnification (35×) without the use of dyes or transillumination (118). Von Arx et al (119) compared the observations of structures on resected root surfaces between an endoscope with an impression of the surface taken at the time of the procedure and observed under the scanning electron microscope. They concluded that the observation of a stained resected roots surface with high magnifications accurately identified isthmi, accessory canals, obturation gaps, and chipping of cavity margins but that there was a difference in correctly identified intradentinal cracks. Besides a microscope and endoscope, the use of ultrasonic tips and microinstruments as well as more biologically acceptable root-end filling materials have changed the technical approach significantly (3).

The weighted pooled success rates for TRS (59.0%) from the first part of this meta-analysis and EMS (93.5%) can be considered as a very low and a very high outcome for endodontic surgery, respectively. These cumulative success rates lie on 2 ends of the spectrum and do not reflect the outcome of surgical procedures in which microsurgical instruments and biocompatible filling materials were used, but no high-power magnification was applied. The influence of high-power magnification can be isolated by comparing EMS with CRS. EMS and CRS are defined here as identical approaches to endodontic surgery, except that EMS uses high-power magnification but CRS does not. Tsesis et al (4) published a meta-analysis and systematic review on modern endodontic surgery that included studies that used modern techniques, such as ultrasonic root-end preparation and modern filling materials, but did not identify significant differences in outcome between studies that made use of the microscope, endoscope, or loupes (4). Del Fabbro et al (120) concluded that, based on 3 prospective studies on endodontic surgery, no significant differences in outcome could be found between surgery performed with loupes, microscope, or endoscope. Furthermore, although describing the benefits of the dental operating microscope based on individual studies on endodontic surgery with high success rates (15, 17, 18), a review by Torabinejad et al (121) did not address cumulative success rates for endodontic surgical procedures with or without high magnification. In a prospective study, von Arx et al (122) documented a significant difference between cases undergoing surgery with the use of the endoscope and without. However, in this investigation, the results from studies that made use of the dental operating microscope, which allows for a similar magnification range as the endoscope, were not combined with the endoscopic procedures nor were these studies separated from investigations that used no or only low-magnification devices, such as loupes (122). Similarly, when prognostic data for endodontic surgery were reviewed in the past, results from cases treated by traditional techniques were frequently combined with results from studies in which patients underwent modern surgical procedures (123). This approach is disregarding the effects that modern surgical techniques have on prognosis. Often, differences in techniques could not be or were not identified (4, 120, 124).

Based on the data presented in this meta-analysis, the suggestion that magnification aides have no effect on the prognosis of endodontic surgery could be considered premature in the absence of large-scale randomized controlled trials. There is a high acceptance of the dental operating microscope and endoscope in the endodontic community. Nevertheless, based on the fact that no data were available in the literature, del Fabbro et al (125) could not find scientific evidence of a benefit using a microscope for endodontic treatment in general at that point in time. The authors of the review correctly stated that no objective conclusions could be drawn from the results of the review because no articles were identified in the current literature that satisfied their inclusion criteria, which pointed out the absence of and the need for well-controlled trials.

The data obtained from this meta-analysis showed a weighted pooled success rate of 88.09% after a 1-year follow-up for endodontic surgery with microsurgical instruments and biocompatible filling materials with only loupes or no visualization aids (CRS) with a statistically significant difference to the weighted pooled success rate for endodontic microsurgery with high-power magnification (EMS) of 93.52% after 1 year of follow-up. This is in contrast to a study by von Arx et al (12) who did not find statistically significant differences in the outcome after 1-year follow-up for cases treated with the aid of the endoscope (94.5%) compared with control cases treated with the naked eye and micro-mirrors (88.5%). Similarly, del Fabbro and Taschieri (120) did not find that magnification affects the surgical prognosis positively. Their conclusion was based on 3 prospective studies on endodontic surgery treated with loupes, microscope, or endoscope. One of the 3 included studies (15) was an outcome comparison between surgical cases treated with loupes and cases treated with the endoscope, with nearly similar results for both groups. Both groups were executed by the same surgeons. From a methodological point of view, it could be argued that the groups should have been treated by

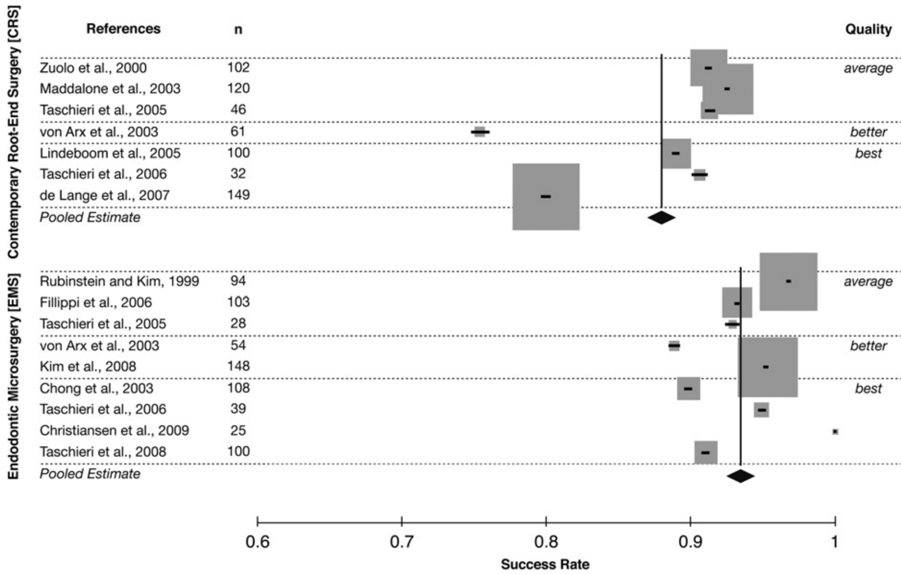


**Figure 1.** Weighted pooled success rates and individual study weights for groups CRS and EMS.

different practitioners. There may have been an adaptation phase after the treatment of cases with high magnification, for instance the anticipation of isthmi in typical clinical situations although not visible by loupes but suspected after the experience with the high-magnification device. In contrast to the present meta-analysis, del Fabbro and Taschieri (120) chose to include only randomized clinical trials. This is a methodological sound approach, yet it also shows the impact of sample size on statistical outcome. The sample sizes of the only studies that could be included in their systematic review and meta-analysis according to the inclusion and exclusion criteria were, as is the case for many clinical trials in dentistry, rather low. In the first of the included articles, the statistical evaluation was based on a sample size of 29 for the endoscope and 24 for loupes-aided surgery (15). The second article (21) was a comparison between the endoscope and microscope; both seeing aids can provide greater than 10× magnification and hence are comparable. Statistical calculations were run with 31 patients in the endoscope and 35 in the microscope group. The third study was by von Arx et al (12) with 45 patients treated with the endoscope and 41 with the naked eye. With only limited available data at hand, the systematic review and meta-analysis had to conclude, that for endodontic surgery no significant difference in outcomes could be found between loupes, microscope, or endoscope and that the type of magnification device per se could only minimally affect the outcome of endodontic treatment (120).

The sample size being too small is a probable reason for data to be not statistically significantly different. The relative absence of large-scale randomized controlled trials in endodontics is one difficulty in identifying "true" outcomes. Mead et al (126) investigated the quality of clinical investigations on the outcome of endodontic surgery and found no level of evidence 1 randomized clinical trials and only 2 level of evidence 2 randomized clinical trials comparing the outcomes of surgical treatment with that of nonsurgical retreatment. The remainder being level of evidence 3 case control studies and a majority of level of evidence 4 low-quality cohort or case series investigations (126). According to the methodology of part 1 of this meta-analysis (2), the aim of this investigation was to provide the best available evidence in the absence of large-scale randomized controlled trials by calculation from extracted raw data from all available publications that fit the inclusion and exclusion criteria of this systematic review, following the example of Ng et al (127). The conclusive evaluation of the differences between EMS, CRS, and TRS in this meta-analysis was based on contingency tables and chi-square tests. Although statistically significant differences existed for every group of teeth (ie, molars, premolars, and anteriors) over all groups (ie, EMS, CRS, and TRS) between the standardized means by applying probits of probabilities and z scores, these were not used as they only apply for continuous data. A z score significance is based on effect sizes differences only, which are based on successes percentages, whereas contingency tables and chi-square tests take the percentages of failures into account as well because they relate more to frequencies and proportions.

The statistical power of the analyses according to individual tooth groups in this part II of the study was low. Power is defined as the ability of an analysis to indicate statistically significance that is truly in the data. Hulley and Cummings (128) discussed the importance of statistical power to reach valid statistically significant conclusions. Therefore, for this investigation preference was given to a larger sample size even if the data were not derived from randomized clinical trials, in lieu of an approach that uses only randomized clinical trials and necessarily relies on a smaller sample size (120, 125). In part I of this meta-analysis, the overall statistical power was 1.0, the highest power achievable (100% power). The sample size for the study (n = 1,624) and the difference between the weighted pooled success rates of TRS versus EMS (34.52%) were both large enough to achieve good power. The analysis of the overall comparison of the CRS versus EMS groups (n = 1,309, a difference in weighted pooled success rates of 5.43%), achieved an adequate power of 0.922. However, power was considerably lower for the analyses on the 3 subgroupings of molars (n = 193, a difference in weighted pooled success rates of 7.71% with a power of 0.497), premolars (n = 169, a difference in weighted pooled success rates of 4.23% with a power of 0.08), and anteriors (n = 277, a difference in weighted pooled success rates of 2.11% with a power of 0.06). Although the power for the molars only analysis was considerably lower than for the overall comparison, the larger difference in the pooled success rates of CRS versus EMS for molars (7.71%) could still be detected as statistically significant. The premolar and anterior differences in weighted pooled success rates were less than 5%, and, therefore, the sample size was not adequate to power these 2 analyses.

From a clinical point of view, the increasing difficulty in anatomy with molars over premolars and anteriors could be a logical explanation for a statistically significant difference between the use of microscope or endoscope versus the naked eye or loupes. Although certain premolars or anteriors may present with complex anatomy, such as canal isthmi or additional canals, the proportions of these findings are much higher in molars. Therefore, the majority of cases with simpler anatomy may mask any significant effects of higher magnification on the treatment of the respective groups at large. To show a statistically significant difference at a 90% statistical power confidence level between 2 groups with a difference in outcome of 10%, comparable to the premolar group, a sample size of 266 cases per group would be necessary (128). The raw data extraction across different studies for the purpose of a meta-analysis allowed for a sample size large enough to show statistically significant differences between cumulative success rates as close as the difference between EMS and CRS with statistical validity.

In conclusion, based on the data presented in this meta-analysis, the probability for success for EMS was significantly greater than the probability for success for CRS ($P < .0005$). The treatment of molars with the microscope or the endoscope seems to be of advantage over treatments without higher magnification. This provided the best available evidence on the influence of high-power magnification provided by the dental operating microscope or the endoscope and the superiority of endodontic microsurgery over contemporary endodontic surgery with no or low magnification. The results from this study also showed the necessity for large-scale randomized clinical trials for statistically valid conclusions for current endodontic questions to make an informed decision for clinical practice.

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