For Teeth Requiring Endodontic Treatment, What Are the Differences in Outcomes of Restored Endodontically Treated Teeth Compared to Implant-Supported Restorations?

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Purpose: *The clinical question this systematic review aimed to answer was "What are the differences in outcomes of restored endodontically treated teeth compared to implant-supported restorations? Therefore the aim of this study was to use systematic review to compare the survival of compromised teeth restored with either root canal therapy followed by a crown, or placement of a single-tooth implant.* ***Materials and Methods:*** *MEDLINE, EMBASE, and PubMed databases were searched for studies dealing with survival of single-tooth implants and restored endodontically treated teeth. A 2-step screening procedure was used to identify articles that met the inclusion/exclusion criteria. Fifty-five studies related to single-tooth implants and 13 studies related to restored root canal–treated teeth were included. The endpoint analyzed in these studies was the survival rate of the treated tooth or implant.* ***Results:*** *The 95% confidence intervals for the pooled estimates for the single-tooth implants and restored endodontically treated teeth were found overlapping in forest plots for all follow-up periods. This indicated no significant differences in survival between restored root canal–treated teeth and single-tooth implants.* ***Conclusions:*** *The results of this systematic review indicate that the decision to treat a tooth endodontically or replace it with an implant must be based on factors other than the treatment outcomes of the procedures themselves. Both nonsurgical root canal therapy followed by an appropriate restoration and single-tooth implants are excellent treatment modalities for the treatment of compromised teeth.* Int J Oral Maxillofac Implants 2007;22(suppl):96–116

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The osseointegrated dental implant concept developed by Brånemark[1] for replacement of missing teeth has become a widely accepted and predictable treatment modality. Creugers and associates[2] performed a systematic review of single-tooth restorations supported by implants with the conclusion that single-tooth implants showed a very acceptable 4-year survival rate of 97%. As a result of this, implants have been considered equitable treatment with root canal therapy as a viable option for compromised teeth. Implant placement has become a viable treatment option for the management of nonvital compromised teeth. However, the decision to restore a compromised tooth with an implant or perform root canal treatment followed by appropriate restoration depends on the clinical judgment of the practitioner. It is therefore possible that some teeth that have been removed could have been successfully treated with endodontic therapy, while others have been treated with root canal therapy when replacing them with implants would have been a better option.

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An early consensus conference on dental implants in 1979, prior to the international introduction of osseointegrated implants, cautioned that marketing was driving this emerging technology into uncontrolled and widespread use.[3] There is a great deal of concern regarding potential underuse or overuse of many medical and surgical procedures.[4] With regard to the placement of dental implants, this concern is, at least in part, a result of the dearth of literature comparing the success rate of implants versus root canal treatment. Systematic reviews of literature have in the past yielded reproducible estimates of the survival of dental treatments.[5] A systematic review comparing the success rates of restored endodontically treated teeth versus implants could be of great interest to patients, dental professionals, and dental insurance companies. Therefore, the aim of this study was to systematically review clinical studies of the survival of single-tooth implants and endodontically treated and restored teeth and to compare the results.

MATERIALS AND METHODS

The Academy of Osseointegration's 2006 workshop on the state of the science of implant dentistry entrusted the authors of this review to systematically review the literature to answer the following question, framed in a PICO format (problem, intervention, comparison, and outcome): "What are the differences in outcomes of restored endodontically treated teeth compared to (single tooth) implant-supported restorations?" The methodology involved in this systematic review included literature search and selection, inclusion/exclusion of studies, quality assessment, and statistical analysis.

Identification of Studies

We searched MEDLINE, EMBASE, and PubMed for the period from January 1981 to May 1, 2005 for published data on single-tooth implants using the following medical subject headings (MeSH terms) and combinations thereof: "dental," "implant," and "single." This, combined with the studies received from the Academy of Osseointegration, led to a total of 1,797 studies on implants. To find studies on endodontically treated teeth, both MeSH terms and free-text words were used, including the key words "conventional root canal treatment," "root canal therapy," "restored teeth," "outcome," "prognosis," and "survival." Websites dealing with dental implants and root canal treatment and reference lists in published articles were manually searched. A total of 430 studies on restored endodontically treated teeth were identified for initial screening. Of the single-tooth implant studies that were retrieved through this search, only those that examined survival as an outcome were selected. The selection of studies on single-tooth implants was based on the criteria listed in Table 1. With respect to endodontic studies, only those from which data related to clinical survival of the root canal–treated teeth restored with crowns could be extracted were selected. The detailed selection criteria for restored root canal–treated teeth are listed in Table 2. The success/survival criteria for implants are listed in Table 3. Root canal–treated teeth were considered to be surviving if they were present in the mouth. Failure was assumed if the tooth had been extracted or extraction was planned. Great efforts were undertaken to obtain the survival rates of restored root canal–treated teeth from studies before their exclusion, and a number of times the authors of the study were contacted.

Methods of Review and Quality Assessment

The titles and abstracts of all reports identified through the electronic searches were assessed independently by 2 reviewers to establish whether the studies met the inclusion criteria. Studies rejected at subsequent stages were recorded in the table of excluded studies, and the reasons for exclusion were recorded. The literature search yielded a total of 1,797 citations for dental implants. After the titles and abstracts were screened, 1,712 were excluded. Full-text copies of the remaining 85 studies were obtained for more detailed evaluation.[2,6–89] Of the 85 identified by the literature search, 55 single-tooth implant studies[6–60] met the inclusion criteria for the systematic review (Table 4). The reasons for excluding the other 30 studies[2,61–89] from the analysis are reported in the Web edition of this article. Similarly the titles and abstracts of 430 citations for restored endodontically treated teeth were screened, and the full text of 46 studies[17,90–134] was retrieved for detailed analysis. Only 13 studies[17,90–101] met the inclusion criteria (Table 5). The reasons for exclusion of the remaining 33 studies[102–134] are reported in the Web edition of this article. At the second stage of selection agreement beyond chance on which articles to include or exclude was measured using Cohen's kappa statistic, and any disagreement was resolved by discussion. Based on quality assessment, the studies were stratified into 6 categories: unknown, fair, average, good, better, and best. A study was categorized as "unknown" if the type of study information was left blank during data extraction or the study did not fit into 1 of the following categories: best (randomized controlled trial, double blind), better (prospective study with concurrent

Table 1 Selection Criteria Regarding Papers on Single-Tooth Implants

Step	Inclusion criteria	Exclusion criteria
First selection	Single-tooth implants reported Clinical study Follow-up study	Nonclinical study Case report Description of surgical techniques
Second selection	1. Paper in English 2. Follow-up of 1 year 3. Endpoint shown as failure or survival 4. No. of patients stated 5. Type of implant system stated 6. Sample size ≥ 10	1. One of the inclusion criteria is not met 2. Studies exclusively dealing with overdentures, removable partial dentures, smoking, microbiological comparisons, marginal tissue reactions, barrier membranes and medically compromised patients

Table 2 Selection Criteria Regarding Papers on Restored Root Canal–Treated Teeth

Step	Inclusion criteria	Exclusion criteria
First selection	Root canal treatment reported Clinical study Follow-up study	Nonclinical study Case report Description of surgical techniques
Second selection	1. Paper in English 2. Follow-up of 1 year 3. Type of coronal restoration stated 4. Endpoint shown as extraction or survival 5. No. of patients stated 6. Percentage of teeth that survived could be calculated 7. Sample size ≥10	1. One of the inclusion criteria is not met 2. Used only radiographic criteria for success and failure 3. No full coronal restoration 4. Exclusively dealt with retreatment or surgical endodontics 5. Survival rate was not reported or could not be calculated

controls), good (prospective study with historical controls), average (prospective case study), or fair (retrospective case study).

Outcome Measures and Data Extraction

The main outcome of interest extracted from the studies was survival of the single-tooth implants and restored root canal–treated teeth. Complete failure or loss of a tooth or implant was used as an outcome. All studies that based success exclusively on radiographic findings or criteria other than survival of the implant or tooth were therefore excluded. The selected studies then underwent validity assessment and data extraction separately by 2 reviewers. Any discrepancy in data extraction results was resolved by collectively revisiting the study. During the abstraction process, the data were entered into evidence tables shown in the article by Proskin and associates elsewhere in this issue.

Table 3 Survival/Success Criteria for Implants

Implant survival	Implant success
Implant in place Absence of mobility (if mobility could be measured) Absence of pain Absence of infection	All implant survival criteria met Less than 50% bone loss

Statistics

The Wilson score method was used to determine a 95% confidence interval for each proportion. All studies that reported cumulative proportion for single-tooth implant and restored root canal–treated tooth survival were included in analysis. The overall estimates for single-tooth implant and restored root canal–treated teeth were calculated using the values for last-reported survival. In addition, meta-analysis was also performed at the timepoints of 12, 24, 36, 48, 60, and 72 months. A hypothesis test for the difference between 2 treatments can be performed for 2 individual studies that contained both treatment groups. In this meta-analysis only 1 study contained both treatment groups; therefore, this analysis was not performed. Detailed description on statistical treatment performed in this systematic review can be found in the article by Proskin and colleagues elsewhere in this supplemental issue.

Table 4 Survival Rate of Single-Tooth Implants

Author	Year	Type of study	n	Recall (mo)	Survival (%)
Andersson[6]	1995	Prospective	38	36	100
Andersson[7]	1998	Prospective	65	60	98.5
Andersson[8]	1998	Prospective	38	60	94.4
Becker[9]	1995	Retrospective	23	24	95.7
Becker[10]	1998	Clinical trial	134	96	93.3
Becker[11]	1999	Prospective	282	72	89.5
Bianco[12]	2000	Retrospective	252	96	95.9
Brocard[13]	2000	Prospective	1022	84	92.2
Cordioli[14]	1994	Retrospective	67	60	95.4
Cosci[15]	1997	Retrospective	423	84	99.53
Deporter[16]	1998	Retrospective	20	24	100
Dhanrajani[17]	2005	Retrospective	11	72	96.0
Doyle[18]	2006	Retrospective	96	12	93.9
Ekfeldt[19]	1994	Retrospective	93	55	–
Engquist[20]	1995	Retrospective	82	36	97.6
Gibbard[21]	2002	Prospective	30	70	96.66
Gomez-Roman[22]	1997	Case study	696	54	96.0
Gomez-Roman[23]	2001	Retrospective	124	60	97.0
Haas[24]	2002	Retrospective	76	120	93.0
Henry[25]	1996	Prospective	107	60	98.3
Jemt[26]	1993	Retrospective	70	36	98.5
Johnson[27]	2000	Prospective	59	36	98.3
Kemppainen[28]	1997	Clinical trial	102	12	99.0
Laney[29]	1994	Prospective	95	36	97.2
Ledermann[30]	1993	Prospective	42	36	0.0
Levine[31]	1997	Retrospective	174	40	95.5
Levine[32]	2002	Retrospective	675	78	99.1
Malevez[33]	1996	Retrospective	97	60	97.6
McMillan[34]	1998	Retrospective	76	60	96.0
Morris[35]	2001	Prospective	351	48	95.2
Nentwig[36]	2004	Prospective	943	144	98.7
Norton[37]	2001	Retrospective	14	84	100
Orenstein[38]	2000	Prospective	247	36	97.3
Palmer[39]	2000	Retrospective	15	36	100
Pecora[40]	1996	Retrospective	32	16	96.8
Polizzi[41]	1999	Case study	30	84	93.3
Priest[42]	1999	Retrospective	119	120	97.5
Rodriguez[43]	2000	Prospective	2900	36	98.1
Rosenquist[44]	1996	Retrospective	109	35	93.6
Scheller[45]	1998	Prospective	99	60	95.95
Schmitt[46]	1993	Retrospective	40	72	100
Schropp[47]	2005	Prospective	23	24	91.0
			23	24	96.0
Schwartz-Arad[48]	1999	Retrospective	78	60	92.3
Schwartz-Arad[49]	2000	Retrospective	56	96	89.0
Simon[50]	2003	Retrospective	126	10	96.0
Smith[51]	1992	Retrospective	313	54	94.25
Taylor[52]	2004	Retrospective	39	60	97.4
Thilander[53]	1999	Retrospective	15	96	100
Tolman[54]	1991	Case study	303	60	99.34
Vehemente[55]	2002	Retrospective	677	60	90.20
Vermylen[56]	2003	Retrospective	43	84	100
Vigolo[57]	2000	Retrospective	52	60	94.2
Watson[58]	1999	Prospective	33	48	100
Wennstrom[59]	2005	Prospective	45	60	97.7
Zinsli[60]	2004	Retrospective	298	72	94.1

Table 5 Survival Rate of Root Canal Treatment Followed by Coronal Restoration

Author	Year	Type of study	n	Recall (mo)	Survival (%)
Alley[90]	2004	Retrospective	297	60	94.6
Aquilino[91]	2002	Retrospective	157	120	89.0
Bergman[92]	1989	Retrospective	96	72	96.876
Dammaschke[93]	2003	Retrospective	190	120	92.2
Doyle[18]	2006	Retrospective	196	120	93.9
Hatzikyriakos[94]	1992	Retrospective	154	36	95.45
Lazarski[95]	2001	Retrospective	19,817	72	97.34
Linde[96]	1984	Retrospective	51	120	81.2
Lynch[97]	2004	Retrospective	48	60	91.9
Mannocci[98]	2002	Retrospective	117	36	100
Mentink[99]	1993	Retrospective	516	58	98.26
Sorensen[100]	1985	Retrospective	1,273	300	97.55
Tilashalski[101]	2004	Retrospective	59	48	88.0

RESULTS

Studies were most commonly excluded because they did not provide sufficient data to calculate the survival rate of restored root canal–treated teeth. Fifty-five studies met the inclusion criteria for implants, 13 for the restored endodontically treated teeth; 1 included study contained both treatment groups. Flowcharts for study selection progression are shown in Figs 1 and 2. The majority of articles selected were published in 1990 or later (Fig 3). The quality assessment results as shown in Fig 4 indicate that the majority of the articles fell into "fair" category; only a few were rated as "better." The kappa value for agreement between the 2 reviewers in evaluation of the implant studies was 0.866; for endodontic studies, a slightly higher value of 0.893 was obtained.

Table 4 provides an overview of studies dealing with single-tooth implants. The number of subjects in each study arm ranged from 99 to 1,007, and outcome results were provided at multiple time periods ranging from 12 to 144 months. The list contains 2 clinical trials, 3 case studies, 18 prospective and 40 retrospective studies. In 1 study both single-tooth implants and restored root canal–treated teeth were studied.

Table 5 provides an overview of studies dealing with restored root canal–treated teeth. Most of the endodontic studies were retrospective in nature, and no clinical trials were present. The timepoints of outcome assessment were generally single and ranged from 36 to 300 months. Number of subjects in each arm of the studies ranged from 48 to 19,817. The median follow-up period for single-tooth implant studies was 5 years; for restored root canal–treated teeth, it was 7.8 years.

The forest plots for the meta-analysis of implant and endodontic studies at different time periods are shown in Figs 5 to 11. These figures also stratify studies according to quality assessment. The pooled estimates based on all the studies are represented by the vertical gray lines, and the 95% confidence intervals for the pooled estimate are represented by the gray diamonds. The confidence intervals for proportion estimates for different time periods for implant and endodontic studies are presented in Table 6. The 95% confidence intervals for the pooled estimate for the single-tooth implants and restored endodontically treated teeth can be found overlapping in forest plots for all time periods. This indicated that there was no difference in the survival rates between the 2 treatment modalities.

DISCUSSION

This review was undertaken to attempt to determine what the differences in outcome are between restored endodontically treated teeth compared to single-tooth implants with restorations.

The results of this systematic review indicated that there is no difference in the survival outcome between these 2 treatment modalities. Therefore the decision to treat a compromised tooth endodontically or replace it with an implant must be based on factors other than treatment outcome. These results are similar to a recent study that evaluated the survival rate of single-tooth implants and restored endodontically treated teeth in the same setting.[16] According to this study restored endodontically treated teeth and single-tooth implant restorations

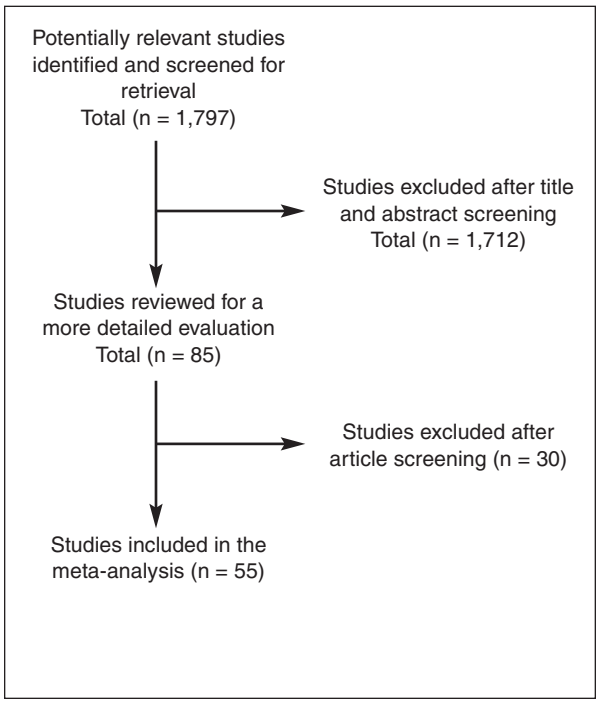


Fig 1 Single-tooth implant study selection progression.

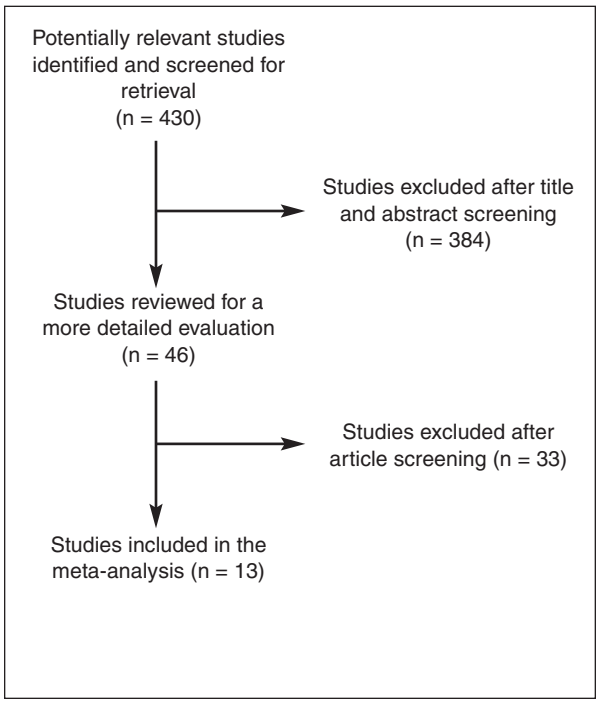
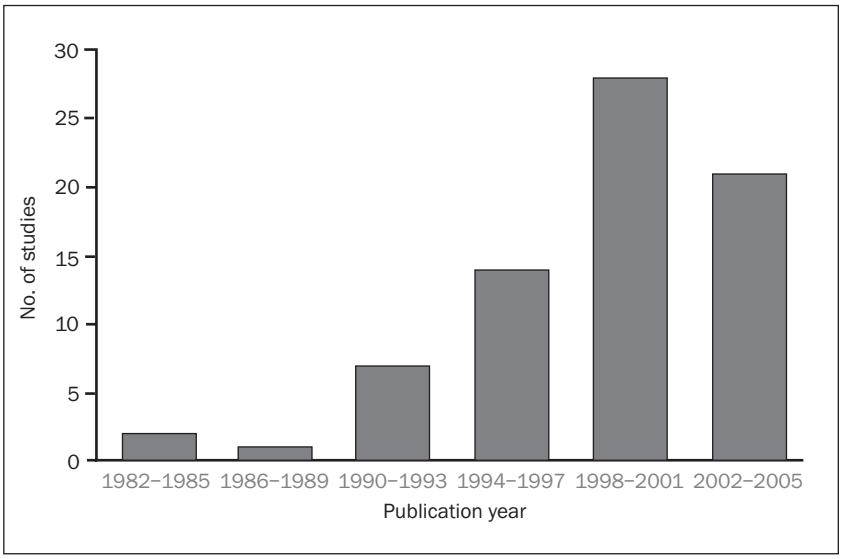


Fig 2 Root canal treatment study selection progression.

Fig 3 Article distribution by year.



have similar failure rates, although the implant group had a longer average time in function and a higher incidence of postoperative complications that required treatment.

The term *endodontically treated teeth* encompasses a broad range of treatment categories that are associated with different treatment outcomes. As judged by radiographic criteria, the success rate of endodontically treated teeth without apical periodontitis (periapical radiolucency) is higher than teeth with apical periodontitis. Furthermore, the retreatment of a failing root canal treatment has been associated with the lowest success rate.[110] Ideally the outcome of each of these categories (initial treatment without apical periodontitis, initial treatment with apical periodontitis, nonsurgical and surgical retreatment of failing root canal treatment) needs to be individually compared to implants. However, at present the survival rates of these categories of endodontic therapy with coronal restorations are

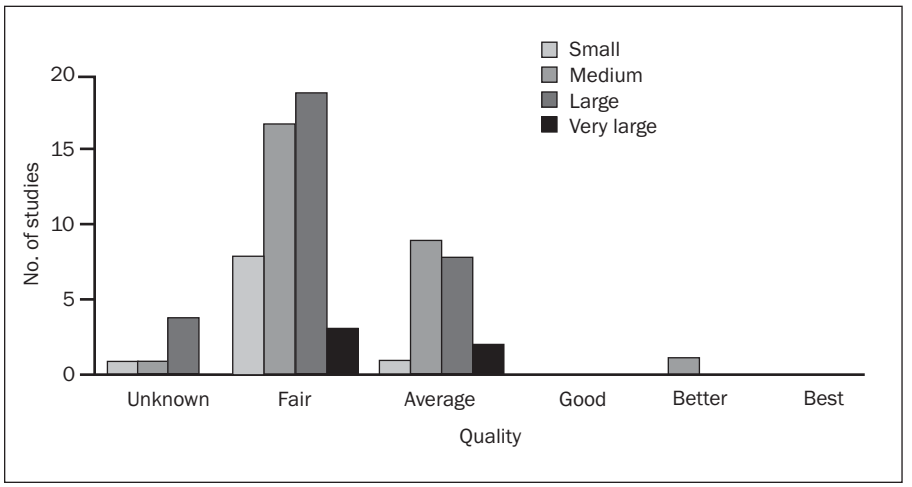


Fig 4 Quality and size of studies.

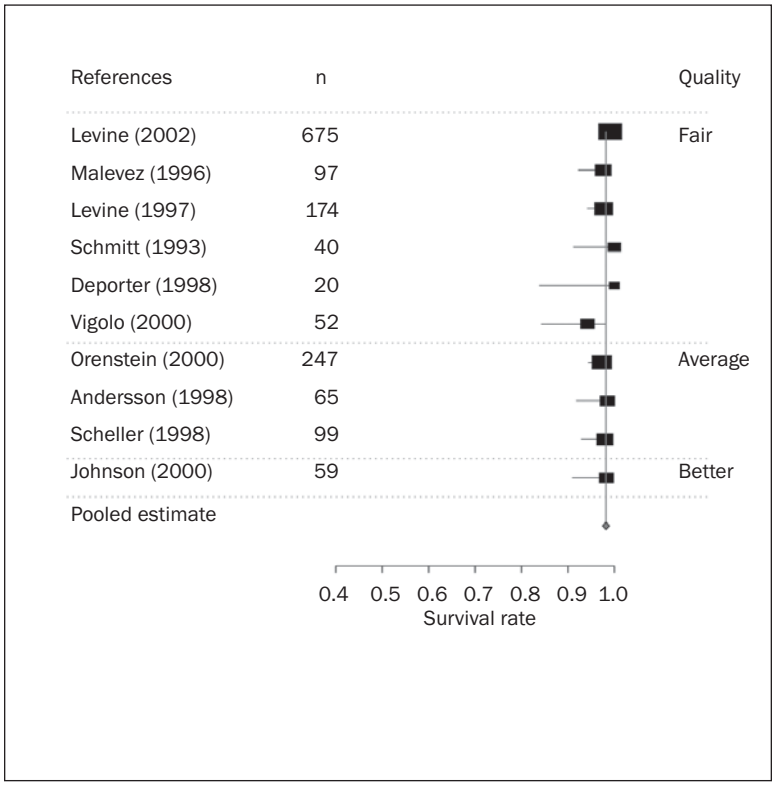


Fig 5 Implant survival rate at the 6-month examination.

not available in literature. The endodontic studies included in this systematic review did not specify the type of endodontic treatment performed on the teeth prior to their restoration, and it is not known whether these studies represented a broad range of endodontic therapies. The terms *endodontically* or *root canal–treated teeth* are used interchangeably in this review and represent teeth that received nonsurgical root canal treatment.

Similarly, the term *dental implant* embodies a number of different types of implants. Only single-tooth implants were analyzed in this review so that the data for the 2 groups would be comparable. The data included in this review were derived from studies dealing with single dental implants only as well as from some larger studies in which single dental implants constituted 1 of the study arms. Although this approach has its limitations, it was believed that evaluating and consolidating all available data would result in more meaningful conclusions.

A systematic review requires that the authors restrict themselves to information that is comparable

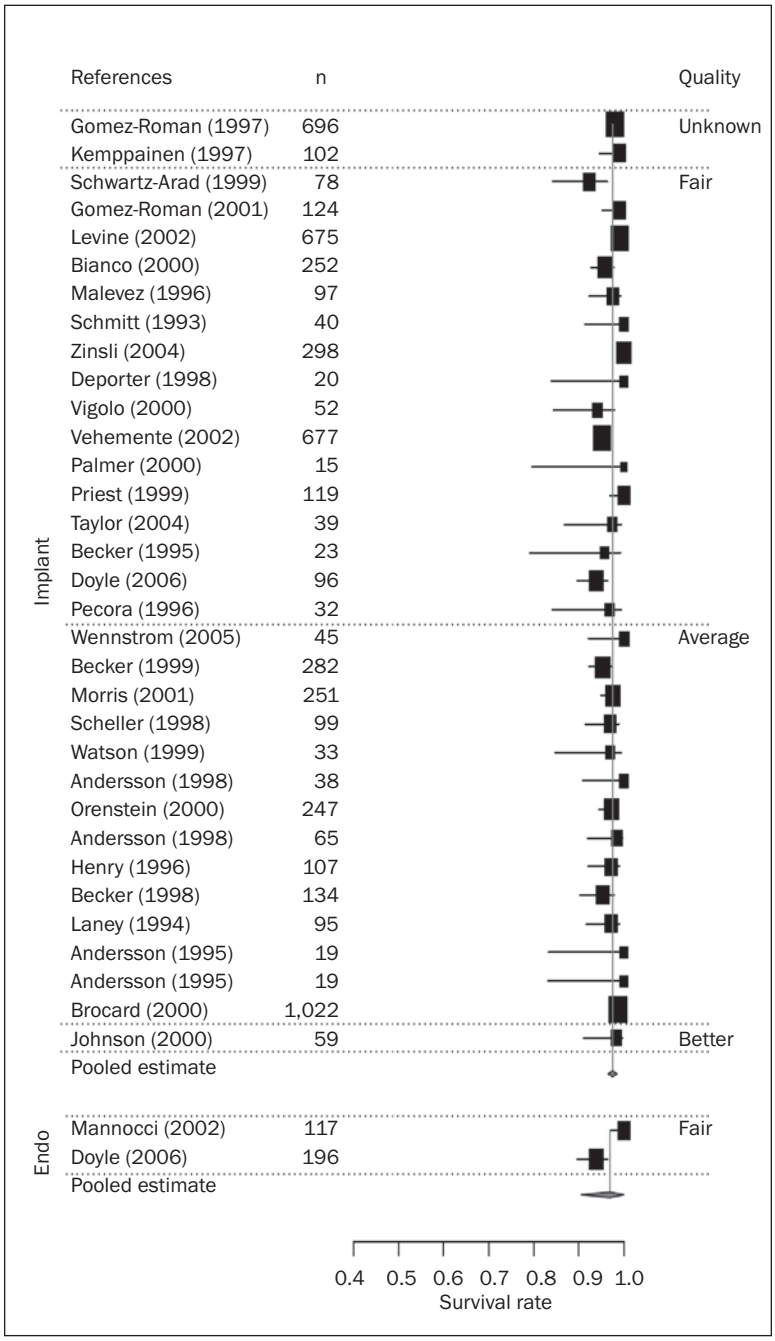


Fig 6 Implant/tooth survival rate at the 12-month examination.

between studies. Comparison of endodontically treated teeth and dental implants was confounded by a number of variables. Foremost among these is the fact that widely different criteria were used to measure the success rates of implants and root canal treatment. Despite the presence of comparatively strict criteria,[135] the success of implants has been primarily judged by their survival and functionality in the mouth. On the other hand, the success of root canal treatment has been traditionally assessed by stringent criteria, including presence or absence of periapical radiolucencies, clinical function, and histopathological evaluation of biopsied tissue. Thus, in contrast to dental implants, a functionally normal root canal–treated tooth will be categorized as failure if periapical radiolucency is associated with it. In essence, the use of lenient success criteria in implant studies may translate to higher success rates, while stringent criteria employed in root canal prognostic studies may lead to lower success rates. Therefore, this systematic review used only those studies that investigated the survival of endodontically treated

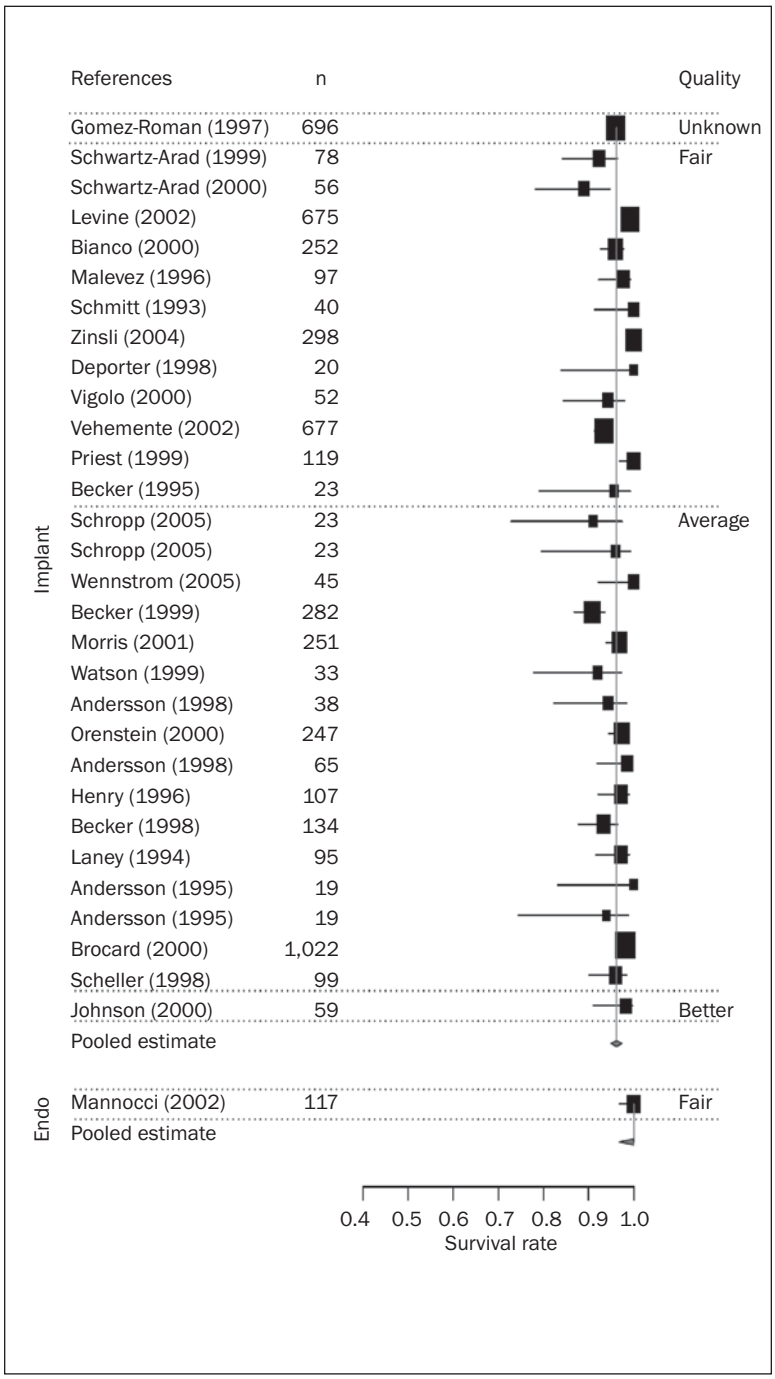


Fig 7 Implant/tooth survival rate at the 24-month examination.

teeth; as a result, a large number of endodontic studies could not be included.

During the last 50 years, many outcome studies have been performed on root canal–treated teeth. Partly because the influence of many concomitant factors, such as coronal restorations and proximal contacts, has not been accounted for, and partly because of dissimilarities in criteria for success and failure, these studies have yielded widely disparate results. The type of restoration provided for root canal–treated teeth is considered a major determinant of its survival. In 1 study, 85% of root canal–treated teeth that were extracted had not been properly restored.[124] In another study, endodontically treated teeth not restored with crowns after canal obturation were extracted at a rate 6.0 times greater than teeth crowned after obturation.[91] In a study by Sorensen and Martinoff,[100] the greatest failure proportion (24.2%) was reported for root canal–treated teeth without crowns. Therefore,

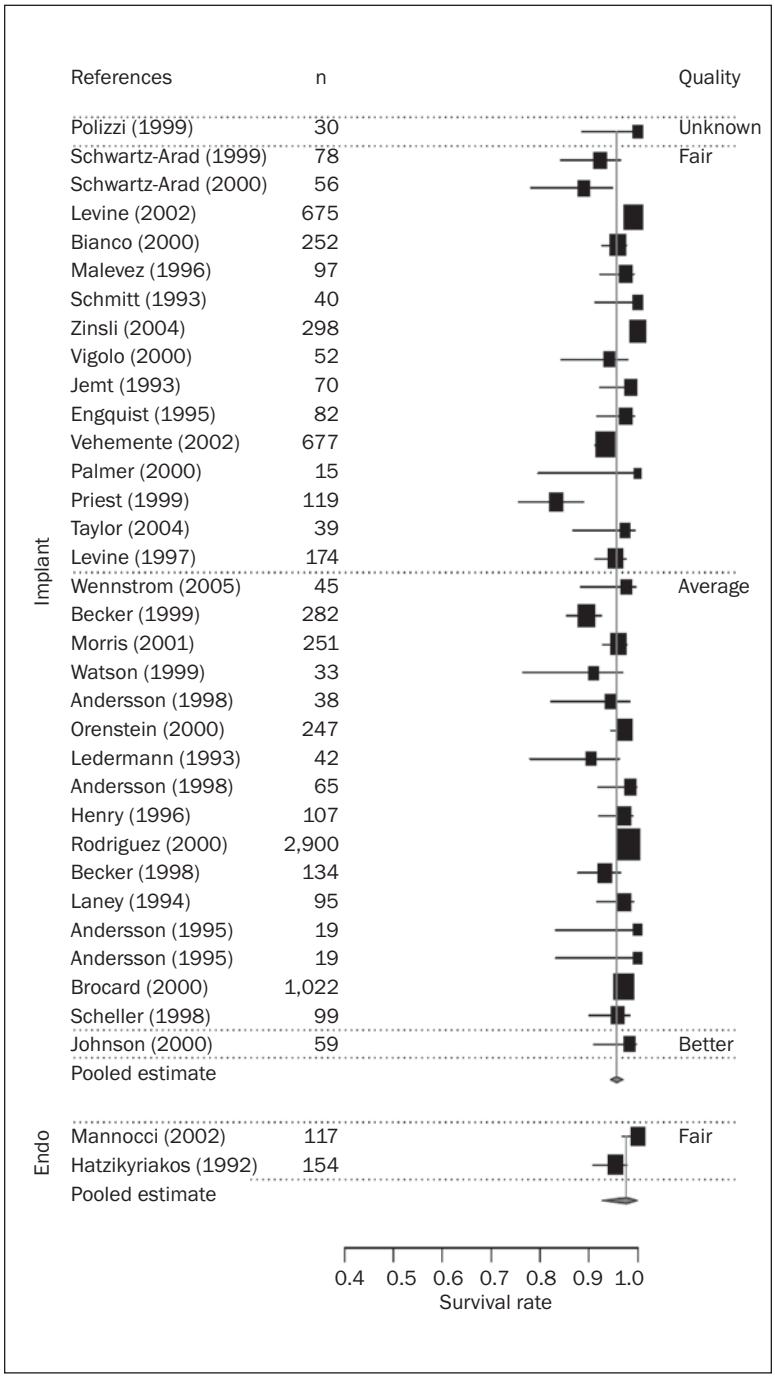


Fig 8 Implant/tooth survival rate at the 36-month examination.

to conduct a valid comparison, in the present reviews, prosthetically restored implants were compared with prosthetically restored endodontically treated teeth. Only a few studies were identified that included a study arm containing restored endodontically treated teeth and survival data, which led to further exclusion of a number of endodontic studies.

Both the implant and endodontic studies included in this systematic review were conducted using material from previous decades and therefore reflect the treatment approaches prevalent at that time. Recently there have been tremendous improvements in both implant dentistry and endodontic techniques and materials. In technological terms, "modern" endodontics can be considered as advanced as implant dentistry. It is difficult to assess the extent to which these improvements (eg, the increasing use of nickel-titanium rotary instruments, electronic apex locators, surgical operating microscopes and newer materials for endodontics, new

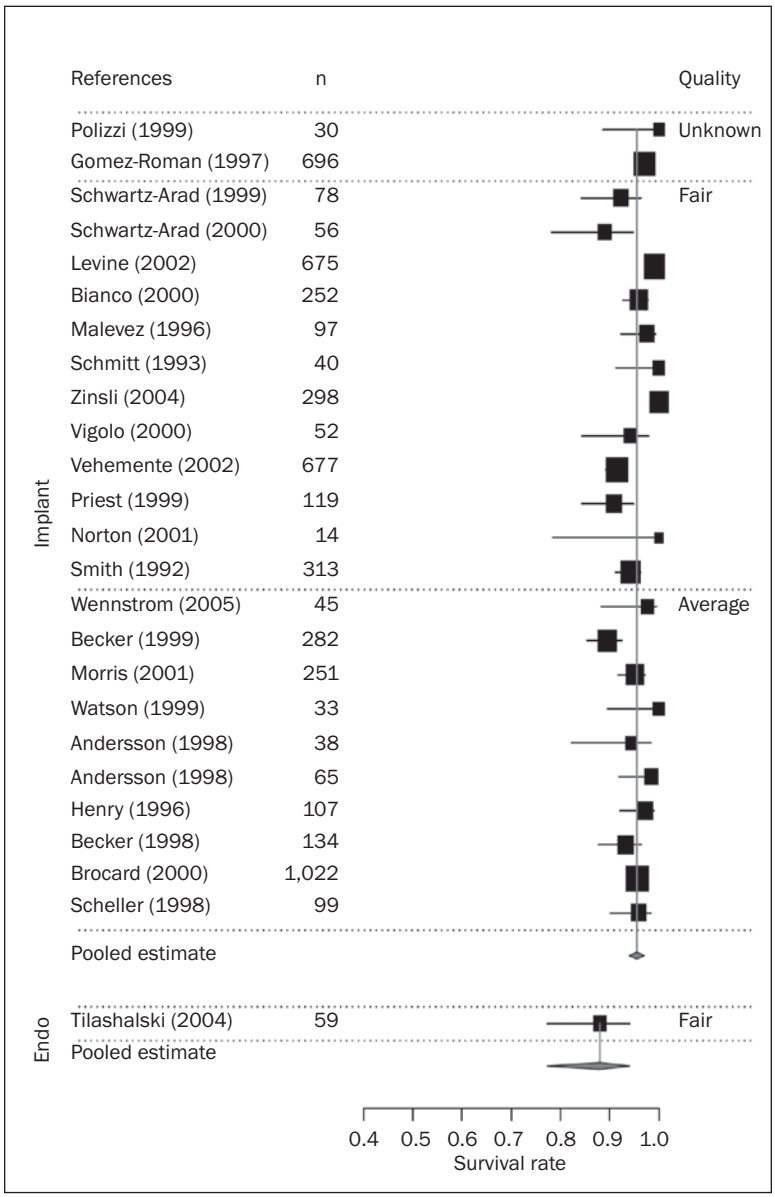


Fig 9 Implant/tooth survival rate at the 48-month examination.

implant materials, implant surface modifications, new implant-abutment interfaces) would affect the survival and/or success rates of root canal–treated teeth compared with single-tooth implants.

One should apply the results of the studies evaluated in this review to clinical practice with caution because the patients, study conditions, and practitioners were not always representative of the clinical population at large. A number of studies included in the endodontic literature were conducted on patients treated by dental students.[91–93,97,99] It is realized that the studies may reflect a certain degree of publication bias (the greater likelihood of the publication of positive findings in comparison to the publication of negative findings). Publication bias is more likely to exist when a particular brand of implant is being studied. Root canal treatment and the restoration of a tooth are mostly generic in nature and [16,90–101] are less likely to suffer from publication bias.

Although it is possible to identify studies that deal exclusively with single-tooth implants, the majority of endodontic studies do not analyze or specify the type of coronal restoration. Single-tooth implants are usually placed to replace individualized missing teeth and are more likely to be adjacent to natural teeth. Conversely, endodontically treated teeth are less likely to be supported by adjacent dentition. Indeed, endodontic studies usually do not distinguish

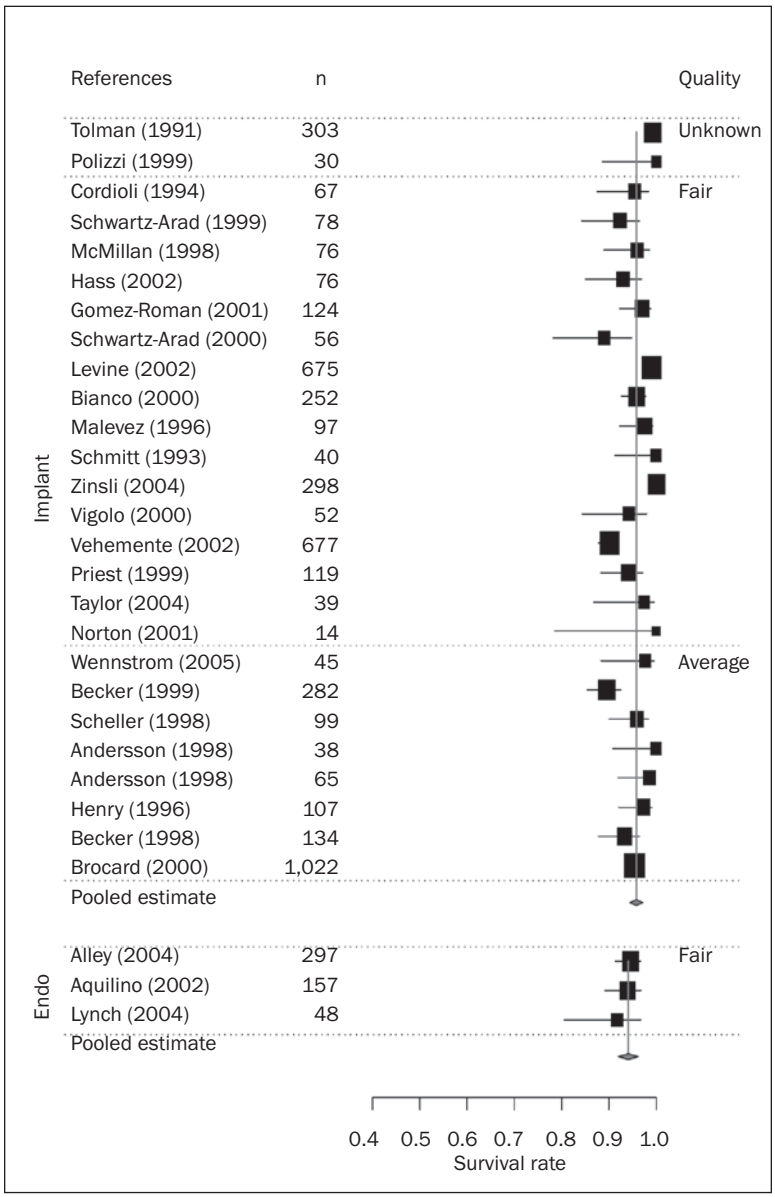


Fig 10 Implant/tooth survival rate at the 60-month examination.

between teeth serving as single crowns or abutments. A review of the literature reveals that root canal–treated teeth that serve as abutments or are not supported by adjacent dentition have a poorer prognosis.[104] Despite these differences, no significant differences in the survival rate of these 2 treatment modalities were found in the present review.

There are important limitations for the observations of this systematic review. A systematic review requires the studies whose data are pooled to be similar in nature. To achieve this similarity, only survival data of root canal–treated teeth were used, rather than the traditionally used success criteria based on radiographic and clinical interpretation. As stated earlier, this led to exclusion of many studies because they did not provide sufficient data to compute survival rates of restored root canal–treated teeth. Conversely, few studies were found that identified the type of coronal restoration but failed to use survival criteria for outcome assessment. The results of this review might have been different if these data had been available. Implant-tooth survival rates at some of the time periods are represented by only 1 or 2 studies dealing with restored endodontically treated teeth (Figs 5 to 11). The relatively small number of included studies related to restored endodontically treated teeth might have influenced the result of this analysis.

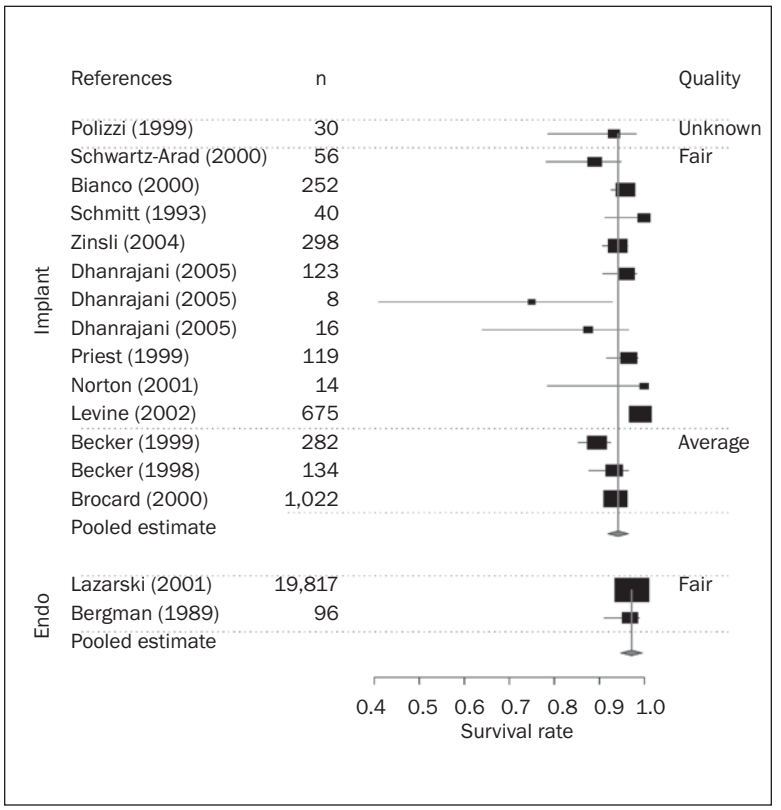


Fig 11 Implant/tooth survival rate at the 72-month examination.

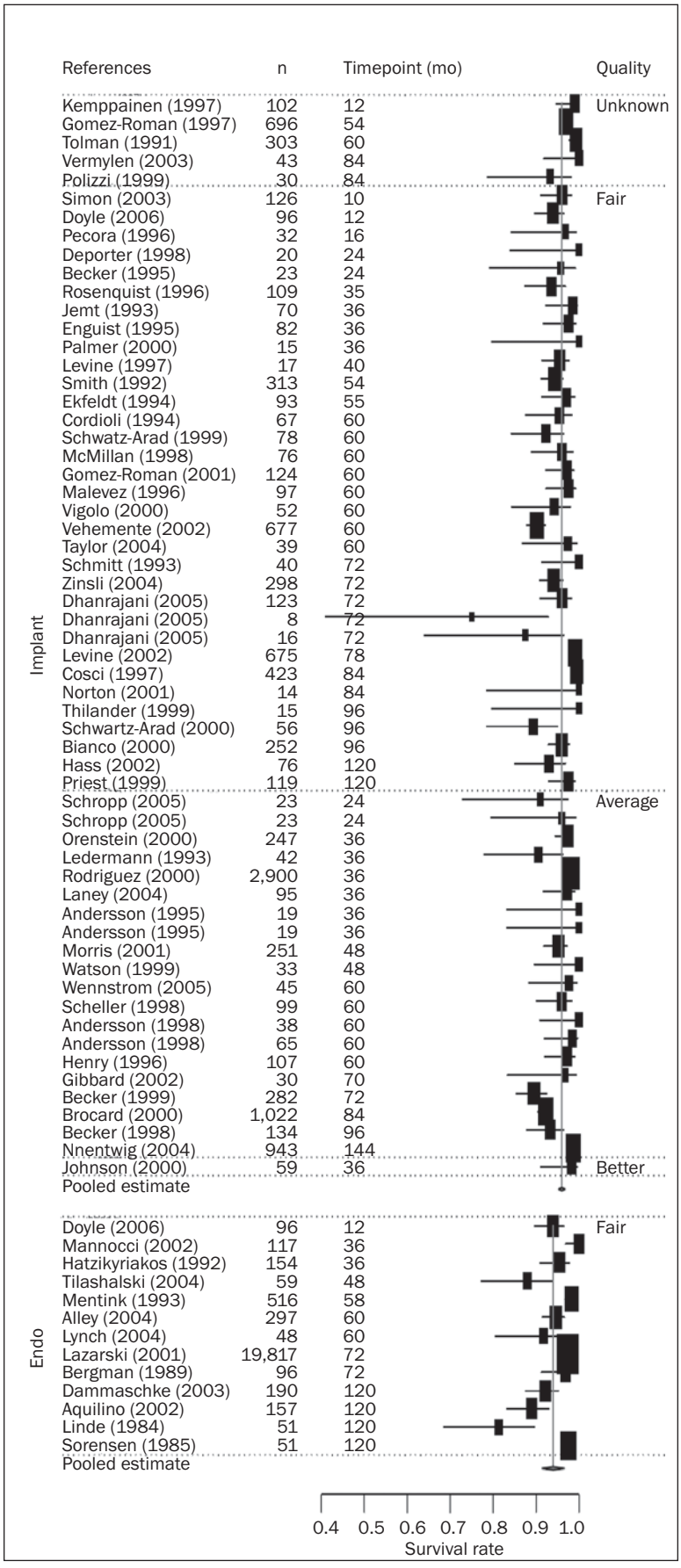
Table 6 Proportion Estimate with Confidence Intervals

Month/ treatment	Proportion estimate	Confidence interval
6		
Implant	0.982	0.975–0.989
Endodontic	—	—
12		
Implant	0.975	0.965–0.985
Endodontic	0.969	0.905–1.000
24		
Implant	0.962	0.950–0.974
Endodontic	1.000	0.968–1.000
36		
Implant	0.957	0.944–0.970
Endodontic	0.977	0.926–1.000
48		
Implant	0.955	0.939–0.971
Endodontic	0.880	0.773–0.940
60		
Implant	0.958	0.944–0.972
Endodontic	0.941	0.919–0.963
72		
Implant	0.942	0.920–0.964
Endodontic	0.972	0.948–0.996
Last exam		
Implant	0.960	0.952–0.968
Endodontic	0.940	0.914–0.966

The results of a systematic review are largely influenced by the quality of the individual studies. Given the high prevalence of pulpal disease and the frequency of intervention, it is of special interest to examine the results of high-quality studies whose purpose is to compare the survival of single-tooth implants versus root canal treatment followed by crown placement. Randomized controlled trials, which are considered the gold standard, have important methodologic advantages over observational studies for addressing this question. However, such trials comparing single-tooth implants and restored root canal–treated teeth are not available, and some might find them unethical. Only 1 observational study could be found that compared single-tooth implants and root canal treatment in the same setting. As a result, the majority of studies included in this review were found to be of "fair" quality (Fig 4). A comparison of the quality of studies between 2 treatment groups is shown in Fig 12. The quality of the studies in the single-tooth implant group was superior to the quality of those in the restored root canal–treated group. The final interpretation of the effect this factor will have on conclusions is left to the individual reader.

Systematic reviews inevitably include studies that are somewhat heterogeneous. In this review, a cer-

Fig 12 Last reported implant/tooth survival rate.



tain degree of heterogeneity is expected due to clinical and methodological differences between implant and root canal studies. Endodontic treatment is primarily performed for the treatment and prevention of apical periodontitis. Thus, root canal treatment usually deals with the eradication of infection, while implants are mostly placed into relatively healthy surroundings. Another source of heterogeneity could arise from diversity in the technical expertise of the clinicians. As stated earlier, a number of studies investigating survival of root canal–treated teeth were based on the work of dental students.

Central to this systematic review was the determination of what constitutes appropriate treatment for a compromised tooth. A definitive randomized controlled trial comparing the survival of restored root canal–treated teeth and single-tooth implants would be ideal but far from achievable. A significant limitation of this systematic review was the paucity of available literature on the survival of root canal–treated teeth with coronal coverage. Most of the studies reported radiographic success without accounting for the type of coronal coverage. It is recommended that future studies attempt to provide survival data that are more relevant to current practice. Furthermore, studies should also report raw data to facilitate interpretation of the findings. The coronal restoration of endodontically treated teeth is important and must be used as a definite variable in data analysis. There is a dearth of studies dealing with survival rates of restored endodontically treated teeth, especially those dealing with retreatment, teeth with periapical lesions, and surgical endodontics. In the absence of rigorous scientific data, the effectiveness of the given procedures cannot be determined. These limitations illustrate the need for a standardized approach to the presentation of survival results of restored endodontically treated teeth as well as dental implants.

The choice to replace a single missing tooth can be based on the primary decision that the restorability of the tooth is in doubt.[137] It is beyond the scope of this review to discuss the decision-making process for the treatment of compromised teeth. However, it is important to develop explicit criteria for determination of what constitutes appropriate treatment of a compromised tooth. The development of consensus criteria for these contemporary treatment options through the joint efforts of Academy of Osseointegration and American Association of Endodontists would be considered ideal.

CONCLUSIONS

During treatment planning for a patient one must take into account a complex array of factors. The results of this systematic review indicate that the decision to treat a tooth endodontically or replace it with an implant must be based on factors other than treatment outcome. Nonsurgical root canal therapy followed by an appropriate restoration and single-tooth implants are both excellent and predictable treatments for the retention of compromised teeth. The diverse clinical conditions and available surgical options highlight the need to develop optimal diagnostic and treatment guidelines for compromised teeth. Viable treatment options, including dental implants, will enhance treatment planning when added to the existing range of endodontic treatment options. However, it is the authors' opinion that priority should be given first to treatment modalities that aim at preserving the natural dentition before embarking on extraction and replacement.

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SECTION 4
CONSENSUS REPORT

For teeth requiring endodontic treatment, what are the differences in outcomes of restored endodontically treated teeth compared to implant-supported restorations?

Members of Section 4 evaluated the systematic review on the relative outcomes of endodontically treated teeth as compared to implant-supported restorations. The focused PICO question addressed by the authors, Syngcuk Kim and Mian K. Iqbal, of the evidence-based systematic review is: For teeth requiring endodontic treatment, what are the differences in outcomes of restored endodontically treated teeth compared to implant-supported restorations?

1. Does the section agree that the systematic review is complete and accurate?

The section agreed that the systematic review was complete and accurate. In addition, we believe that this PICO question addresses a critical issue in dental care. However, we note in particular that the PICO question is limited to the restored single-tooth implant and the restored endodontically treated tooth.

The rationale and approach of the systematic review were considered appropriate for evaluating the survival of the restored single-tooth implant and the restored endodontically treated tooth. For this focused question on the restored single-tooth implant and the restored endodontically treated tooth, survival is an appropriate and available outcome measure that permits evaluation of the 2 therapeutic approaches. The literature search and methods are well described, and overall the section believes that the review is thoughtful in considering the PICO question in the context of comprehensive patient care.

2. Has any new information been generated or discovered since the review cutoff time?

There were 2 investigations available after the review cutoff time. The first is a study by Doyle et al (Doyle SL, Hodges JS, Pesun IJ, Law AS, Bowles WR. Retrospective cross-sectional comparison of initial nonsurgical endodontic treatment and single-tooth implants. J Endod 2006;32:822–827), which is the only article that directly compared restored single-tooth implants with endodontically treated teeth with coronal restorations. The conclusions are consistent with the systematic review and the results have been included in the statistical analysis. The second is a review article by Torabinejad and Goodacre (Torabinejad M, Goodacre CJ. Endodontic or dental implant therapy: The factors affecting treatment planning. J Am Dent Assoc 2006;137:973–977) that presented no new data, and therefore was not included in the analysis. However, the expert opinion is consistent with conclusions of the systematic review.

In addition, it is important to note that the results from this systematic review generated implant survival rates quite similar to the implant survival rates reported in the systematic review of Section 3.

3. Does the section agree with the interpretation and conclusion of the reviewers?

The section agrees with the reviewers that the quality and methodology of the published literature were not ideal for addressing this PICO question and therefore the conclusions are suggestive but not definitive. The state of the present literature does not include clinical trials in which the restored endodontically treated tooth and the restored single-tooth implant are randomly allocated to sites where either treatment can be used.

The section agrees with the interpretations and conclusions of the systematic review with the following consideration. We discussed the reviewers' statement that "priority should be given first to treatment modalities that aim at preserving the natural dentition." The section suggests that, in the absence of randomized controlled trials, the choice of therapy between restored single-tooth implants and restored endodontically treated teeth should be based on consideration of treatment complexity and the patient's informed decision, since the systematic review showed both to be viable treatment alternatives. Relevant issues to consider are the practitioner's training/experience and treatment complexity, which may include but are not limited to active caries, systemic illnesses, periodontal prognosis, and costs.

The section recognizes that continued introduction of new technology in both restored single-tooth implants and restored endodontically treated teeth may affect outcome measurements and suggests that continued systematic reviews are necessary to make contemporary clinical decisions.

4. What further research needs to be done relative to the PICO question?

Clinical trials should evaluate health outcomes in the use of implants and endodontically treated teeth that support prostheses randomly allocated to different sites. It is a priority that such research uses validated outcome measures, employs standardized criteria of success, accounts for selected prosthetic restorations, and evaluates risk factors for restored implants and restored endodontically treated teeth. The outcome measures and criteria should address biological, functional, and esthetic factors as well as quality-of-life measures, cost-benefit ratio for placement and maintenance, and adverse effects. The section also suggests that future research should evaluate the effect of implants and endodontically treated teeth on systemic health.

Future research should consider the impact of restoration modalities (eg, post and cores) or other endodontic procedures (eg, primary treatment, retreatment, surgical treatment) on outcomes of endodontically treated teeth. These initiatives should also consider the impact of subsequent treatment on osseointegration and outcomes of restored implants. Retrospective studies may be most valuable in planning prospective randomized controlled trials. All of the above studies should include a focus on observation periods greater than 10 years.

5. How can the information from the systematic review be applied for patient management?

This systematic review confirmed that both restored single-tooth implants and restored endodontically treated teeth have excellent survival rates with average study periods of 5 to 8 years.

There are few comparative studies to guide practitioners and patients where the restored single-tooth implant or the restored endodontically treated tooth are equally possible therapeutic approaches. In such cases, the results of the systematic review suggest that the treatment decision is a matter of clinical judgment and informed patient preference.

WEB ONLY

Table W1 Single-Tooth Implant Studies Excluded from Meta-Analysis and the Basis for Exclusion

Study	Surgical technique	Quality of life	Review/ opinion	Different focus	Other
Andersson[61]		X		X	
Appleton et al[62]				X	
Bakaeen et al[63]					In vitro
Balshi et al[64]				X	
Buser[65]	X				
Carrion and Barbosa[66]			X		
Christensen[67]	X				
Creugers et al[2]			X		
Fugazzotto[68]				X	
Ganeles and Wismeijer[69]			X		
Ghorbani and Pipko[70]	X				
Gomes et al[71]					< 5 patients
Hebel et al[72]			X	X	
Hess et al[73]			X		
Knox et al[74]					< 5 patients
Kosinski[75]	X				
Krennmair and Ulm[76]				X	
Lew et al[77]	X				
Lytle[78]				X	
McArdle and Clarizio[79]	X				
Muftu and Chapman[80]				X	
Nowzari et al[81]	X				Case report
Pohl et al[82]	X			X	
Rounsavelle[83]	X				
Ruskin et al[84]			X		
Tang and Naylor[85]			X		
Toljanic and Baer[86]			X		
Vergara[87]					<10 patients
Vermylen et al[88]		X			
Wöhrle[89]	X				

Table W2 Root Canal–Treated Studies Excluded from Systematic Review and Basis for Exclusion

Study	Exclusion reason			
	Used clinical/ radiographic criteria for success	Survival rate could not be extracted	Coronal restoration not specified	Review/ opinion paper
Barbakow et al[102]	X	X	X	
Caliskan and Sen[103]		X	X	
Caplan and Weintraub[104]			X	
Cheung and Chan[105]	X	X		
Cheung[106]	X	X		
Chugal et al[107]	X	X	X	
Creugers et al[108]				X
Eckerbom et al[109]		X	X	
Friedman[110]				X
Friedman[111]	X	X		
Fristad et al[112]	X	X	X	
Gutmann[113]				X
Jaoui et al[114]	X	X	X	
Kirkevang et al[115]	X	X	X	
Klevant and Eggink[116]	X	X	X	
Meeuwissen and Eschen[117]			X	
Molven et al[118]	X	X	X	
Orstavik et al[119]	X	X	X	
Peak et al[120]	X			
Pekruhn[121]	X	X	X	
Pettiette et al[122]	X	X	X	
Ray and Trope[123]	X	X		
Salehrabi and Rotstein[124]			X	
Sjogren et al[125]	X	X	X	
Smith et al[126]	X	X	X	
Swartz et al[127]	X	X		
Tronstad et al[128]	X	X		
Turner [129]		X		
Valderhaug et al[130]	X	X		
Vire[131]		X	X	
Weiger et al[132]				X
Weine et al[133]		X		
Willershausen et al[134]	X	X		