Outcomes of root canal treatment and restoration, implant-supported single crowns, fixed partial dentures, and extraction without replacement: A systematic review

Mahmoud Torabinejad, DMD, MSD, PhD,[a] Patricia Anderson, MILS,[b] Jim Bader, DDS, MPH,[c] L. Jackson Brown, DDS, PhD,[d] Lie H. Chen, MPH,[e] Charles J. Goodacre, DDS, MSD,[f] Mathew T. Kattadiyil, DDS, MDS, MS,[g] Diana Kutsenko, DMD,[h] Jaime Lozada, DDS,[i] Rishi Patel, BDS,[j] Floyd Petersen, MPH,[k] Israel Puterman, DMD,[l] and Shane N. White, BDentSc, MS, MA, PhD[m]
School of Dentistry, and School of Public Health, Loma Linda University, Loma Linda, Calif; Dentistry Library, University of Michigan, Ann Arbor, Mich; School of Dentistry, University of North Carolina at Chapel Hill, Chapel Hill, NC; Health Policy Resources Center, American Dental Association, Chicago, Ill; University of California Los Angeles School of Dentistry, Los Angeles, Calif

Statement of problem. Dentists and patients are regularly confronted by a difficult treatment question: should a tooth be saved through root canal treatment and restoration (RCT), be extracted without any tooth replacement, be replaced with a fixed partial denture (FPD) or an implant-supported single crown (ISC)?

Purpose. The purpose of this systematic review was to compare the outcomes, benefits, and harms of endodontic care and restoration compared to extraction and placement of ISCs, FPDs, or extraction without tooth replacement.

Material and methods. Searches performed in MEDLINE, Cochrane, and EMBASE databases were enriched by hand searches, citation mining, and expert recommendation. Evidence tables were developed following quality and inclusion criteria assessment. Pooled and weighted mean success and survival rates, with associated confidence intervals, were calculated for single implant crowns, fixed partial dentures, and initial nonsurgical root canal treatments. Data related to extraction without tooth replacement and psychosocial outcomes were evaluated by a narrative review due to literature limitations.

[a]Professor of Endodontics, School of Dentistry, Loma Linda University.
[b]Head Librarian, Dentistry Library, University of Michigan.
[c]Research Professor, Department of Operative Dentistry, School of Dentistry, University of North Carolina at Chapel Hill.
[d]Associate Executive Director, Health Policy Resources Center, American Dental Association.
[e]Statistical Programmer, Health Research Consulting Group, School of Public Health, Loma Linda University.
[f]Professor of Restorative Dentistry and Dean, School of Dentistry, Loma Linda University.
[g]Associate Professor of Restorative Dentistry and Interim Director, Advanced Education Program in Prosthodontics, School of Dentistry, Loma Linda University.
[h]Resident, Postgraduate Endodontics, School of Dentistry, Loma Linda University.
[i]Professor and Graduate Program Director of Implant Dentistry, School of Dentistry, Loma Linda University.
[j]Resident, Advanced Education Program in Prosthodontics, School of Dentistry, Loma Linda University.
[k]Assistant Professor, Health Research Consulting Group, Department of Epidemiology and Biostatistics, School of Public Health, Loma Linda University.
[l]Resident, Postgraduate Periodontics, School of Dentistry, Loma Linda University.
[m]Professor, University of California Los Angeles School of Dentistry.

Results. The 143 selected studies varied considerably in design, success definition, assessment methods, operator type, and sample size. Direct comparison of treatment types was extremely rare. Limited psychosocial data revealed the traumatic effect of loss of visible teeth. Economic data were largely absent. Success rates for ISCs were higher than for RCTs and FPDs, respectively; however, success criteria differed greatly among treatment types, rendering direct comparison of success rates futile. Long-term survival rates for ISCs and RCTs were similar and superior to those for FPDs.

Conclusions. Lack of comparative studies with similar outcomes criteria with comparable time intervals limited comparison of these treatments. ISC and RCT treatments resulted in superior long-term survival, compared to FPDs. Limited data suggested that extraction without replacement resulted in inferior psychosocial outcomes compared to alternatives. Long-term, prospective clinical trials with large sample sizes and clearly defined outcomes criteria are needed. (J Prosthet Dent 2007;98:285-311)

Clinical Implications

Limited data suggested that extraction without replacement resulted in inferior psychosocial outcomes compared to alternatives of retention or replacement. Implant and endodontic treatments resulted in superior long-term survival, compared to fixed partial dentures. Success criteria differed greatly among treatment types, rendering direct comparison of success rates unhelpful. Therefore, priority in treatment planning should be given to tooth retention through root canal treatment or to replacement with an implant-supported single crown.

Preservation of the natural dentition has long been a key dental therapeutic goal. The high survival rates of osseointegrated dental implants have created new treatment options. Dentists and patients are regularly confronted by difficult treatment questions necessitating both quantitative and qualitative responses.[1,2] For example, should a tooth be saved through root canal treatment and restoration (RCT), be extracted without any tooth replacement, or be replaced with a fixed partial denture (FPD) or an implant-supported single crown (ISC)? Considerations involved in selecting from among these 4 treatment alternatives have been reviewed and discussed.[3-9] However, direct comparisons of outcomes are limited.[10-13] The available reviews do not compare all of the available alternative treatments for a tooth with pulpal pathology, nor do they consider all of the possible outcomes of such treatments.[14,15]

Evidence-based principles that include identification of specific scientific evidence, assessing its validity, and using the "best" evidence to inform patient care decisions, can affect specialists, general dentists, patients, employers who purchase insurance packages, insurance companies, and policy makers.[16] Treatment decisions must be based on scientific study of clinical outcomes, including clinical, psychosocial, and economic measures.[2,17] Economic methods may be usefully applied to healthcare outcomes questions, because they allow measurement of costs and benefits to individual patients and to society in general.[18-26] Systematic review of the existing literature can provide an objective synopsis of the best available evidence that can help dentists and their patients make these choices.[27] Systematic reviews are inherently less biased, more reliable, and more valid than narrative reviews.[28,29]

The purpose of this study was to conduct a systematic review of the clinical, psychosocial, and economic outcomes, as well as beneficial and harmful effects, of initial nonsurgical endodontic care, compared to extraction and placement of an implant, fixed partial denture, or extraction without tooth replacement. This project was developed in response to an American Dental Association Foundation request for proposals.

MATERIAL AND METHODS

A systematic review was developed following established guidelines.[29] Methodology included: formulating review questions using a PICO (Patient Population, Intervention, Comparison, and Outcome) framework; constructing a search strategy; defining inclusion and exclusion criteria; locating studies; selecting studies; assessing study quality; extracting data and forming an evidence table; and interpretation.

Formulating the review questions

The PICO framework was used to formulate the following 3 questions for a systematic review of the existing literature. These 3 questions represent an adaptation of 2 questions originally in the American Dental Association Foundation request for proposals: (1) In patients with periodontally sound teeth that have pulpal and/or periradicular pathosis, does initial nonsurgical root canal therapy, compared to extraction without replacement of the missing tooth, result in better (more beneficial) or worse (more harmful) clinical and/or biological outcomes, psychosocial outcomes, and economic outcomes? (2) Similarly, does root canal therapy, compared to extraction and replacement of the missing tooth with a fixed partial denture, result in better or worse outcomes? And, (3) Similarly, does root canal therapy, compared to extraction and replacement of the missing tooth with an implant-supported restoration, result in better or worse outcomes?

Inclusion and exclusion criteria

Inclusion criteria included comparative or noncomparative, prospective or retrospective, longitudinal data related to clinical, biological, psychosocial, and economic outcomes, as well as beneficial or harmful effects of saving teeth by root canal treatment and/or alternative treatments. Inclusion criteria for paper review included: articles published in English from January 1966 to September 2006; adult subjects; secondary teeth; initial treatment; implant-supported single crowns; threaded, cylindrical implants regardless of surface type; minimum of 2-year follow-up (RCT - from obturation; ISC - from implant placement; FPD - from cementation) with treatment units described as being individual ISCs, short-span FPDs of 3 to 4 units, and RCT teeth (not individual roots); with a minimum of 25 treatments (not patients). Publication in a peer-reviewed journal was not an inclusion criterion, because the best available evidence or data is not always found therein. For example, authors are often directly contacted for their raw data during the systematic review process.[27-29]

The exclusion criteria consisted of studies that failed to meet the above inclusion criteria; RCTs due to trauma; treatment modalities not currently being used; moderate or severe periodontal disease; grey literature (proceedings of conferences not listed in MEDLINE, Cochrane, and EMBASE databases, meetings, and lectures); studies without clinical, psychosocial, or economic outcomes; and implant studies on completely edentulous patients.

Search methodology

Electronic searches were performed in MEDLINE, Cochrane, and EMBASE databases, with the results enriched by hand searches, citation mining, and expert recommendation. Hand searches involved reviewing the tables of contents for every issue of the most recent 2 years of the following journal titles, which represented 50% of the total number of original research articles in English from the past 5 years for the ISC, FPD, and RCT topics: *American Journal of Dentistry*, *Clinical Implant Dentistry and Related Research*, *Clinical Oral Implants Research*, *Dental Materials*, *Dental Traumatology*, *Implant Dentistry*, *International Endodontic Journal*, *International Journal of Oral and Maxillofacial Implants*, *International Journal of Periodontics and Restorative Dentistry*, *International Journal of Prosthodontics*, *Journal of Dentistry*, *Journal of Endodontics*, *Journal of Periodontology*, *The Journal of Prosthetic Dentistry*, *Journal of Oral and Maxillofacial Surgery*, *Journal of Oral Rehabilitation*, *Operative Dentistry*, *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics*, and *Quintessence International*.

The citation mining and expert recommendation process incorporated relevant materials that may not appear in a MEDLINE search on the topic, such as book chapters or review articles. External experts were consulted to recommend additional articles or books for review. Other database searches, including Cochrane and EMBASE, were designed as permutations of the successful MEDLINE search strategy.

Search strategies were developed for 3 disciplines: implants, fixed prosthodontics, and endodontics (Figs. 1 through 3). For each discipline, collaborative searching strategies were developed among a librarian, the subject expert, a consultant, and the principal investigator. Each search began with selection of 10 or more sentinel articles. The articles were selected to represent the sorts of articles that should be retrieved by a good MEDLINE search for that topic. The sentinel articles were restricted to the inclusion and exclusion criteria.

The sentinel articles served as seed articles to suggest appropriate MeSH (Medical Subject Headings) and free text terms for the searches.[30] These headings and terms were enriched by terms suggested and reviewed jointly by the information expert and the domain expert for that topic. For the final search strategies, the filters were combined with primary clinical outcomes; the Rochester/Miner etiology and prognosis filters enriched with selected research methodology terms, and the limits and/or exclusion criteria (Fig. 4).[31,32] Following the initial search strategies on primary clinical outcomes, a second search was performed for each of the ISC, FPD, and RCT disciplines to retrieve results on psychosocial outcomes (Fig. 5).

Search strategies were reviewed for quality by verifying the inclusion of the sentinel articles. If any sentinel articles were not included, the reason for the loss was identified, and the search process was reviewed and revised by the domain expert and information expert in consultation with the principal investigators. The revised search was then tested again for validity. The abstracts of these articles were then reviewed based on these inclusion and exclusion criteria. Valid systematic search strategies for the effects of extraction without tooth replacement and for economic outcomes were not achieved due to limitations of the available literature and indexing terms. Therefore, these topics were limited to hand searches, citation mining, and expert recommendations.

(((exp Dental Implants/ or exp Dental Implantation/ or Dental Prosthesis, Implant-Supported/ or Osseointegration/ or Implants, Experimental/ or "Prostheses and Implants"/) and (exp Jaw/ or exp Jaw Diseases/ or exp Jaw Abnormalities/ or exp Mouth, Edentulous/)) or (exp Dental Implants/ or exp Dental Implantation/ or Dental Prosthesis, Implant-Supported/)) or (((((dental or oral or maxillofacial or jaw) adj3 implant$1).mp. or osseointegrat:.mp. or (peri-implant: or periimplant:).mp. or "implant-supported".mp. or (implant adj (tooth or tissue) adj support:).mp. or (implantology or implantologia or implantologie).mp. or ((hollow adj (screw$2 or cylinder$1)) or (HS or HC)).mp.) and (exp Jaw/ or exp Jaw Diseases/ or exp Jaw Abnormalities/ or exp Mouth, Edentulous/)) or (surgi: adj3 dental adj3 prosthe:).mp. or ((single-tooth or subperiosteal or endosseous or occlusal or periapical) adj3 implant:).mp.) or ((branemark.ti,ab. or 3i.mp. or Anthogyr.mp. or "Astra Tech". mp. or Bicon.mp. or BioHorizons.mp. or BLB.mp. or Calcitek.mp. or conical.mp. or transmucosal.mp. or "conventional cast".mp. or (friatec: or friadent or frialit:).mp. or Impla-Med.mp. or IMTEC.mp. or IMZ.mp. or ITI. mp. or "laser-welded".mp. or Lifecore.mp. or ((Mk or Mark) adj (II or III or IV)).mp. or (MKII or MKIII or MKIV). mp. or Micro-Lok.mp. or "morse taper".mp. or novum.mp. or Omnilock.mp. or Paragon.mp. or Restore.mp. or screw-shaped.mp. or "Screw Vent".mp. or self-tapping.mp. or splinted.mp. or Stargrip.mp. or Steri-Oss.mp. or Sulzer.ti,ab. or TBR.mp. or Tenax.mp. or TiUnite.mp. or titanium.mp. or unsplinted.mp. or zygomaticus.mp. or ((dental or implant) adj (protocol or system or framework)).mp.) and (exp Jaw/ or exp Jaw Diseases/ or exp Jaw Abnormalities/ or exp Mouth, Edentulous/) and ((dental or implant) adj (protocol or system or framework)). mp.) and (Clinical Protocols/ or exp Clinical trials/ or exp Patient Care Management/ or Patient Selection/ or Practice Guidelines/ or clinic:.mp. or (recall adj3 appointment$1).mp. or ((patient or research) adj3 (recruitment or selection)).mp. or (selection adj3 (criteria or treatment or subject$1)).mp. or (treatment adj protocol$1). mp. or ra.fs. or radiograph:.mp. or ah.fs. or histolog:.mp. or (nonsurg: or non-surg:).mp. or exp "Quality of Life"/ or ((surviv$3 or fail$3 or success$3) adj rate).mp. or "Denture Retention"/ or Dental prosthesis retention/ or exp Wound Healing/) and (exp Disease progression/ or exp Morbidity/ or exp Mortality/ or exp "Outcome assessment (health care)"/ or exp Patient satisfaction/ or exp Prognosis/ or exp Survival analysis/ or exp Time factors/ or exp Treatment outcome/ or ((beneficial or harmful) adj3 effect$).mp. or co.fs. or course.mp. or (inception adj cohort$1).mp. or (natural adj history).mp. or outcome$1.mp. or predict$.mp. or prognos$.mp. or surviv$3.mp. or fail$5.mp. or longevity.mp. or durability.mp. or succes:.mp. or random$.ti,ab. or predispos$. ti,ab. or causa$.ti,ab. or exp Case-control studies/ or (case$1 adj control$).ti,ab. or exp Cohort studies/ or exp "Comparative study"/ or exp Epidemiological Studies/ or odds ratio/ or (odds adj ratio$1).ti,ab. or exp Risk/ or risk$.ti,ab. or Meta-analysis/ or Meta-analysis.pt. or practice guideline.pt. or exp Clinical Trials/ or (randomized controlled trial or controlled clinical trial).pt. or random$.ti,ab. or (systematic adj review$1).mp. or Retreatment/ or Recurrence/ or (retreat: or revis:).mp.)

1 Search strategy for single tooth implant studies, without limits.

(((exp Prosthodontics/ or exp Oral Surgical Procedures, Preprosthetic/ or exp Maxillofacial Prosthesis Implantation/ or exp Tooth Replantation/) or ((exp "Prostheses and Implants"/ or (prosthes: or prosthet: or prostho:).mp.) and exp stomatognathic system/) or ((dentur:.mp. or ((dent: or palat$3 or tooth or teeth or molar) adj5 (abut: or clasp$1 or restor: or crown$1 or post$1 or veneer$1)).mp.) and exp stomatognathic system/) or ((resin adj bonded adj3 prosthes:).mp. or pontic$1.mp. or ((conservative or rochette or maryland) adj bridge$1).mp. or ((cantilever or conservative) adj5 ("fixed partial denture" or FPD)).mp. or (("fixed partial denture" or FPD or bridge or abutment) adj3 retainer).mp. or ((gold or ceramic: or porcelain or resin or PFM or metal: or "all metal" or "all ceramic" or "implant supported" or "implant retained" or "base metal" or "high noble" or alloy) adj5 (crown or restoration)).mp.)) and (Clinical Protocols/ or exp Clinical trials/ or exp Patient Care Management/ or Patient Selection/ or Practice Guidelines/ or clinic:.mp. or (recall adj3 appointment$1). mp. or ((patient or research) adj3 (recruitment or selection)).mp. or (selection adj3 (criteria or treatment or subject$1)).mp. or (treatment adj protocol$1).mp. or ra.fs. or radiograph:.mp. or ah.fs. or histolog:.mp. or (nonsurg: or non-surg:).mp. or exp "Quality of Life"/ or ((surviv$3 or fail$3 or success$3) adj rate).mp. or "Denture Retention"/ or Dental prosthesis retention/ or exp Wound Healing/) and (exp Disease progression/ or exp Morbidity/ or exp Mortality/ or exp "Outcome assessment (health care)"/ or exp Patient satisfaction/ or exp Prognosis/ or exp Survival analysis/ or exp Time factors/ or exp Treatment outcome/ or ((beneficial or harmful) adj3 effect$).mp. or co.fs. or course.mp. or (inception adj cohort$1).mp. or (natural adj history).mp. or outcome$1.mp. or predict$.mp. or prognos$.mp. or surviv$3.mp. or fail$5.mp. or longevity.mp. or durability. mp. or succes:.mp. or random$.ti,ab. or predispos$.ti,ab. or causa$.ti,ab. or exp Case-control studies/ or (case$1 adj control$).ti,ab. or exp Cohort studies/ or exp "Comparative study"/ or exp Epidemiological Studies/ or odds ratio/ or (odds adj ratio$1).ti,ab. or exp Risk/ or risk$.ti,ab. or Meta-analysis/ or Meta-analysis.pt. or practice guideline.pt. or exp Clinical Trials/ or (randomized controlled trial or controlled clinical trial).pt. or random$. ti,ab. or (systematic adj review$1).mp. or Retreatment/ or Recurrence/ or (retreat: or revis:).mp.) and (single:.mp. or immediate:.mp. or bound:.mp. or pontic:.mp. or (abut: adj (teeth or tooth)).mp.))

2 Search strategy for fixed partial denture studies, without limits.

((exp Endodontics/ or exp Dental Pulp Diseases/ or exp Periapical Diseases/ or exp "Root Canal Filling Materials"/ or Dental Pulp Test/ or Dental Pulp/ or Dental Pulp Cavity/) or (("root canal".mp. or apicectom:.mp. or apicoectom:.mp. or (dead adj3 (teeth or tooth)).mp. or (dental adj3 pulp:).mp. or endodont:.mp. or endont:.mp. or endosonic.mp. or ((lateral or vertical) adj condensation).mp. or ((non-vital or nonvital) adj3 (teeth or tooth)).mp. or obtura.mp. or obturation.mp. or obturate.mp. or (pulp adj3 (capping or therap: or extirpation:)).mp. or (pulp adj (canal$1 or chamber$1)).mp. or pulpectomy.mp. or pulpotomy.mp. or replantation.mp. or ("root" adj end adj5 fill:).mp. or ((silver or gutta) adj3 (percha or balata)).mp. or (silver adj (cone$1 or point$1)).mp. or thermafil.mp. or trans-polyisoprene.mp. or transpolyisoprene.mp. or ultrafil.mp.) or ((periradicular or radicular or periapical or apical).mp. and (exp tooth/ or exp tooth components/))) not (*Apicoectomy/ or *Dental Implantation, Endosseous, Endodontic/ or *Retrograde Obturation/ or *Tooth Replantation/)) and (Clinical Protocols/ or exp Clinical trials/ or exp Patient Care Management/ or Patient Selection/ or Practice Guidelines/ or clinic:.mp. or (recall adj3 appointment$1).mp. or ((patient or research) adj3 (recruitment or selection)).mp. or (selection adj3 (criteria or treatment or subject$1)).mp. or (treatment adj protocol$1).mp. or ra.fs. or radiograph:.mp. or ah.fs. or histolog:.mp. or (nonsurg: or non-surg:).mp.) and (exp Disease progression/ or exp Morbidity/ or exp Mortality/ or exp "Outcome assessment (health care)"/ or exp Patient satisfaction/ or exp Prognosis/ or exp Survival analysis/ or exp Time factors/ or exp Treatment outcome/ or ((beneficial or harmful) adj3 effect$).mp. or co.fs. or course.mp. or (inception adj cohort$1).mp. or (natural adj history).mp. or outcome$1.mp. or predict$.mp. or prognos$.mp. or surviv$3.mp. or fail$5.mp. or longevity.mp. or durability.mp. or succes:.mp. or random$.ti,ab. or predispos$.ti,ab. or causa$.ti,ab. or exp Case-control studies/ or (case$1 adj control$).ti,ab. or exp Cohort studies/ or exp "Comparative study"/ or exp Epidemiological Studies/ or odds ratio/ or (odds adj ratio$1).ti,ab. or exp Risk/ or risk$.ti,ab. or Meta-analysis/ or Meta-analysis.pt. or practice guideline.pt. or exp Clinical Trials/ or (randomized controlled trial or controlled clinical trial).pt. or random$.ti,ab. or (systematic adj review$1).mp. or Retreatment/ or Recurrence/ or (retreat: or revis:).mp.)

3 Search strategy for endodontic studies, without limits.

([N] not ((Dentition, Primary/ or (immatur: adj3 (teeth or tooth)).mp. or (open adj3 (apex or apices or apexes)).mp. or blunderbuss.mp. or limit [N] to (preschool child <2 to 5 years> or child <6 to 12 years>)) not (Dentition, Mixed/ or Dentition, Permanent/ or Adolescent/ or (mature adj3 (teeth or tooth)).mp. or (closed adj3 (apex or apices or apexes)).mp. or limit [N] to all adult <19 plus years>)) not (Animal/ not Human/)) limit [X] to English language

NOTE: The above formula describes the limits applied to each of the three topic searches where [N] represents the final set number of the search to which the limits are applied, and [X] represents the current set containing all limits.

4 Search strategy; limits applied to all topic searches.

([X] and (Dental anxiety/ or odontophobia.mp. or ((dental or dentist:) adj5 (anxi: or phob: or fear)).mp. or ((Fear/ or Anxiety/) and (exp Dentistry/ or exp Stomatognathic System/ or exp Stomatognathic diseases/)) or ("Quality of Life"/ or exp Consumer Satisfaction/ or Attitude/ or ((consumer$1 or patient$1) adj5 (satisf: or preference$1 or accept:)).mp.))

NOTE: The above formula describes each of the three searches for psychology outcomes, where [X] represents the topic search complete with all limits.

5 Search strategy for psychosocial outcomes, applied to all topic searches.

Study selection

First, 3 teams composed of 6 investigators (2 from each discipline) independently screened the titles and abstracts of all articles identified in the electronic and hand searches for each of the 3 disciplines. Articles that did not meet the search criteria were excluded upon reviewers' agreement. Second, all remaining articles were full-text reviewed by the 3 teams independently in the second stage of the process. An independent committee of experts, 2 from each discipline, reviewed the final list to ensure that the inclusion criteria made sense, given the existing literature, and that key studies were not missed. A log of excluded studies and the reasons for exclusion was also developed. In case of disagreement, consensus was reached based on a predetermined protocol for resolving disagreements between reviewers.[17] The independent committee of experts approved the final list.

Study quality rating

A 31-question data abstraction form was developed. The questions related to basic information including: study type (such as prospective/retrospective and clinical trial), number of patients, number of units (teeth/implants/prostheses), study setting, age range of patients, length of follow-up, and specific outcomes and data regarding the types of complications encountered during and after these procedures.[33] This form was also used to assess internal validity by recording information about elements of randomization, concealment of treatment allocation, blinding, and the handling of patient attrition. From the abstracted information, an overall study quality rating score was developed.

Each paper was given a quality score with a maximum possible score of 17 points.[34,35] The evaluators assigned points as follows: randomized clinical trial (4); nonrandomized clinical trial (3); clinical trial with no controls or cohort (2); case-control or case series (2). One point was given for each of the following: total number of enrolled subjects stated; sample size predetermined; operator experience stated; demographic description included; treatment procedures completely described; evaluator different from the operator; complete description of subject loss; treatment complications described; measurements standardized; evaluation methods clearly described; intention to treat stated; and the description and appropriateness of statistical techniques and stratification.

Data extraction for the evidence table

Each team independently extracted data and created a table of evidence from articles that met the validity criteria for each discipline. Within each team, the 3 reviewers independently assessed the studies, then discussion and consensus was used to resolve any disagreements. Interpretation of outcome data, classification of data as to success or survival, and the type of study were subsequently verified by 2 statisticians. Due to great disparities among criteria, the many unique systems used, general lack of commonality, and often limited description, it was not possible to usefully and succinctly tabulate the success criteria used. The data abstraction form was expanded to allow detailed objective data such as number of patients and teeth/implants/prostheses, study design, primary and secondary outcomes, and population sampled to be assembled for selected studies. The independent committee of experts (2 from each discipline) reviewed and approved the final evidence tables.

Data analysis

Quantitative and qualitative methods were used to integrate the evidence without necessarily being guided by a specific predetermined protocol, so as to accommodate the strengths and weaknesses of the collected data and to best provide clinically relevant conclusions. The data were analyzed by deciding whether and what data to combine; measuring the statistical heterogeneity of the data using Cochrane Q and I^2 statistics; assessing the potential for bias; and presenting the results in the form of tables and figures that compare the included studies.[36,37] The Cochrane Q statistic is a simple, widely used estimate of between-study variability, but it has poor power when few studies are included, and excessive power to detect clinically unimportant heterogeneity when many studies are included. The I^2 statistic is a useful indicator of the proportion of total variation in study estimates that is due to heterogeneity.

Data abstraction, analysis, and interpretation were severely constrained by limitations in the existing literature. Success and survival rates sometimes had to be calculated by the reviewers either because they were not directly provided, or because only a particular data subset met the inclusion criteria. In some instances, it was not clear if the outcome measures were crude or cumulative. Thus, crude and cumulative estimates were combined. Other limitations included marked variability in success criteria, variation in or absence of the reporting of complications and adverse effects, considerable variation in follow-up time, lack of life table reporting, and lack of direct comparison of treatment modes.

For comparative purposes, clinical outcomes were grouped into 3 follow-up intervals: 2-4 year, 4-6 year, and over 6 years. For each discipline and follow-up interval, individual studies were displayed in a Forest plot with Wilson Score 95% confidence intervals. The Wilson Score method is a refinement of the simple asymptotic method designed to provide enhanced coverage and increased aberration avoidance.[38] Meta-analyses produced pooled point and 95% confidence interval estimates of success and survival using the DerSimonian-Laird random effects pooling method, as well as by simple weighting. This pooling method is appropriate for comparison of heterogeneous data, but less well suited to large and disparate sample sizes. Conversely, weighting is unsuited to strongly heterogeneous data, but is well suited to large and disparate sample sizes.

Although papers containing psychosocial and economic outcomes did meet the inclusion criteria, their variability precluded meaningful systematic abstraction and analysis. Therefore, psychosocial and economic outcome data were limited to narrative review. Outcomes of the effects of extraction without replacement were even more limited, again necessitating narrative review. Interpretation of data relating to the trauma of extraction itself was considered to be beyond the scope of this review.

RESULTS

Description of the existing literature

Initial electronic and manual searches identified 4361 ISC studies, 3340 FPD studies, and 5346 RCT studies. Following title and abstract screening, full texts for 327 ISC studies, 229 FPD studies, and 347 RCT studies were obtained. Following full-text review for clinical outcomes, 46 ISC papers (Table I), 31 FPD papers (Table II), and 24 RCT papers (Table III) were included. Sixteen articles regarding the effects of tooth extraction without replacement were identified (Table IV). In addition, 27 studies regarding psychosocial effects of these treatment types were identified (Table V). Few articles addressing economic outcomes were identified; several of these addressed psychosocial issues, and are all included within Table V. Root canal treatment studies appeared to be the most mature outcomes literature with usable studies first appearing in 1979, followed by FPD studies in 1984, and most recently by ISC studies in 1993. Few articles comparing treatment modes were located; these were listed in Table V.

Major sources of heterogeneity included reporting of results from differing areas of the mouth; comparison of differing materials and techniques within studies; differing follow-up times; reporting units, teeth, implants, or crowns; differing outcomes measures; differences in operator type; and major variations in patient selection or sample size. Examination of the Cochrane Q and I^2 revealed that all testable strata, except for implants at 4-6 years, were significantly heterogeneous.

Study design varied among the 3 types of treatment. Endodontic outcomes tended to be more frequently described by more rigorous studies than the other disciplines. There were few randomized controlled studies within treatment types, only 1 for ISCs, 1 for FPDs, and 3 for RCTs. Only 4 ISC, 4 FPD, and 7 RCT papers reported the use of controls. Where comparisons were made, they were generally among various techniques or materials. Overall, less rigorous case-series analyses dominated the included articles; they comprised 64% of ISC articles, 71% of FPD articles, and 40% of RCT articles. Prospective designs were included in 62% of ISC, 38% of FPD, and 66% of RCT studies. Only 13% of the ISC studies had an evaluator that was different than the operator. In contrast, FPD and

Table I. Evidence table summary for single tooth replacement by implant-supported single crowns (ISCs). Pooled and weighted success and survival rates, with their associated 95% confidence intervals (CI), were calculated using DerSimonian-Laird random effects model

ISC SUCCESS Authors	Year Published	Time in Years	Sample Size	Number Successful	Success Rate in %	Wilson Score Interval	Quality Score
Schmitt and Zarb[69]	1993	2-4	40	40	100	95-96	6
Karlsson et al[70]	1997	2-4	47	47	100	96-97	8
Polizzi et al[71]	2000	2-4	38	35	92	80-96	4
Norton[72]	2004	2-4	28	27	96	85-97	9
Tsirlis[73]	2005	2-4	43	43	100	95-97	5
Zarone et al[74]	2006	2-4	34	33	97	87-97	9
	Pooled Success Rate (95% CI)				98 (95-99)		
	Weighted Success Rate (95% CI)				99 (96-100)		
Henry et al[75]	1996	4-6	107	104	97	93-99	7
Scheller et al[76]	1998	4-6	99	95	96	90-98	10
Polizzi et al[77]	1999	4-6	30	28	93	80-96	8
Gibbard and Zarb[78]	2002	4-6	30	30	100	93-95	9
Mayer et al[79]	2002	4-6	71	70	99	93-99	8
Prosper et al[80]	2003	4-6	111	108	97	93-99	9
Covani et al[81]	2004	4-6	163	156	96	92-98	10
Nentwig[82]	2004	4-6	943	934	99	98-99	3
Anner et al[83]	2005	4-6	45	45	100	95-97	5
Wennstrom et al[84]	2005	4-6	45	44	98	90-98	10
	Pooled Success Rate (95% CI)				97 (96-98)		
	Weighted Success Rate* (95% CI)				98 (97-99)		
Fugazzotto et al[85]	2004	6+	979	930	95	94-96	4
Levin et al[86]	2005	6+	51	47	93	83-96	7
	Pooled Success Rate (95% CI)				95 (93-96)		
	Weighted Success Rate (95% CI)				95 (93-97)		

TABLE I. *continued* (2 of 2) Evidence table summary for single tooth replacement by implant-supported single crowns (ISCs). Pooled and weighted success and survival rates, with their associated 95% confidence intervals (CI), were calculated using DerSimonian-Laird random effects model

ISC SURVIVAL Authors	Year Published	Time in Years	Sample Size	Number Surviving	Survival Rate in %	Wilson Score Interval	Quality Score
Jemt and Pettersson[87]	1993	2-4	70	69	99	93-99	8
Cordioli et al[88]	1994	2-4	67	64	95	88-98	7
Levine et al[89]	1999	2-4	157	150	96	92-98	7
Moberg et al[90]	1999	2-4	30	29	97	86-97	7
Wannfors and Smedberg[91]	1999	2-4	80	79	99	94-99	7
Johnson and Persson[92]	2000	2-4	59	58	98	92-98	8
Rodriguez et al[93]93	2000	2-4	209	205	98	95-99	5
Mangano and Bartolucci[94]	2001	2-4	80	77	96	90-98	7
Krennmair et al[95]	2002	2-4	146	142	97	94-99	8
Norton and Wilson[96]	2002	2-4	40	36	89	76-94	6
Andersson et al[97]	2003	2-4	42	41	98	89-98	8
Groisman et al[98]	2003	2-4	92	86	94	87-97	6
Block et al[99]	2004	2-4	74	70	95	97-97	5
Ottoni et al[100]	2005	2-4	46	35	76	63-85	9
Schropp et al[101]	2005	2-4	46	43	94	84-97	8
	Pooled Survival Rate (95% CI)				95 (93-97)		
	Weighted Survival Rate (95% CI)				96 (94-97)		
Malevez et al[102]	1996	4-6	84	82	98	92-99	3
Andersson et al[103]	1998	4-6	38	38	100	95-96	9
Andersson et al[104]	1999	4-6	65	64	99	93-99	8
Romanos and Nentwig[105]	2002	4-6	58	56	97	89-98	1
Merischke-Stern et al[106]	2002	4-6	109	108	99	96-99	8
Morris et al[107]	2003	4-6	251	238	95	92-97	7
Covani et al[81]	2004	4-6	163	158	97	93-98	10
Dhanrajani and Al-Rafee[108]	2004	4-6	147	138	94	89-96	6
	Pooled Survival Rate (95% CI)				97 (95-98)		
	Weighted Survival Rate (95% CI)				97 (95-98)		
Scholander[109]	1999	6+	259	254	98	96-99	9
Bianco et al[110]	2000	6+	252	242	96	93-98	7
Bianchi and Sanfilippo[111]	2004	6+	116	116	100	98-99	10
Doring et al[112]	2004	6+	275	270	98	96-99	3
Vigolo et al[113]	2004	6+	192	182	95	91-97	7
Pjetursson et al[114]	2005	6+	214	199	93	89-96	5
	Pooled Survival Rate (95% CI)				97 (95-99)		
	Weighted Survival Rate (95% CI)				97 (96-98)		

TABLE II. Evidence table summary for single tooth replacement by fixed partial dentures (FPDs). Pooled and weighted success and survival rates, with their associated 95% confidence intervals (CI), were calculated using DerSimonian-Laird random effects model

FPD SUCCESS Authors	Year Published	Time in Years	Sample Size	Number Successful	Success Rate in %	Wilson Score Interval	Quality Score
Eshleman et al[115]	1984	2-4	39	33	85	71-92	4
Cheung et al[116]	1990	2-4	169	134	79	73-85	10
Olin[117]	1991	2-4	103	90	87	80-92	6
Kellett et al[118]	1994	2-4	54	26	49	36-61	9
Verzijden et al[119]	1994	2-4	201	139	69	63-75	11
Hussey and Linden[120]	1996	2-4	142	125	88	82-92	7
Sorensen et al[121]	1998	2-4	61	41	67	55-77	6
Botelho et al[122]	2002	2-4	82	78	95	89-98	9
	Pooled Success Rate (95% CI)				79 (69-87)		
	Weighted Success Rate (95% CI)				78 (76-81)		
Reuter and Brose[123]	1984	4-6	121	104	86	79-91	7
Hansson and Moberg[124]	1992	4-6	34	32	93	81-97	8
De Kanter et al[125]	1998	4-6	210	111	53	46-60	5
Walter et al[126]	1999	4-6	47	45	95	85-97	12
Chai et al[125]	2005	4-6	210	172	82	77-87	12
Oginni[128]	2005	4-6	76	54	71	60-80	7
Wolfart et al[129]	2005	4-6	81	75	93	85-96	12
Marquardt and Strub[130]	2006	4-6	31	25	81	65-90	6
	Pooled Success Rate (95% CI)				82 (71-91)		
	Weighted Success Rate (95% CI)				76 (74-79)		
Karlsson[131]	1986	6+	238	221	93	89-96	6
Valderhaug[132]	1991	6+	108	82	76	67-83	9
Priest[133]	1995	6+	77	47	61	50-71	4
Keschbaum et al[134]	1996	6+	1637	1310	80	78-82	5
Samama[135]	1996	6+	145	120	83	76-88	2
Libby[136]	1997	6+	89	76	85	77-91	3
Probster and Henrich[137]	1997	6+	325	195	60	55-65	8
Behr et al[138]	1998	6+	120	74	62	53-70	9
Shugars et al[139]	1998	6+	124	117	94	89-97	5
Hochman et al[140]	2003	6+	49	43	88	77-94	8
Holm et al[141]	2003	6+	99	83	84	76-90	8
Olsson et al[142]	2003	6+	42	35	83	70-91	9
Walton[143]	2003	6+	515	474	92	89-94	5
De Backer et al[144]	2006	6+	134	98	73	65-80	8
	Pooled Success Rate (95% CI)				81 (74-86)		
	Weighted Success Rate (95% CI)				80 (79-82)		

FPD SURVIVAL Authors	Year Published	Time in Years	Sample Size	Number Surviving	Survival Rate in %	Wilson Score Interval	Quality Score
Hussey and Linden[120]	1996	2-4	142	133	94	89-97	7
Barrack and Bretz[145]	1993	4-6	127	118	93	87-96	7
Keschbaum et al[134]	1996	6+	1637	1342	82	80-84	5

TABLE III. Evidence table summary for tooth retention by root canal treatment (RCT). Pooled and weighted success and survival rates, with their associated 95% confidence intervals (CI), were calculated using DerSimonian-Laird random effects model

RCT SUCCESS Authors	Year Published	Time in Years	Sample Size	Number Successful	Success Rate in %	Wilson Score Interval	Quality Score
Ashkenaz et al[146]	1979	2-4	58	57	98	92-98	9
Rudner and Oilet[147]	1981	2-4	104	95	91	85-95	4
Oliet[148]	1983	2-4	338	301	89	85-92	9
Teo et al[149]	1986	2-4	385	350	91	87-93	10
Michnowicz et al[150]	1989	2-4	50	48	96	87-98	11
Benenati and Khajotia[151]	2002	2-4	29	28	97	85-97	11
Travassos et al[152]	2003	2-4	397	341	86	82-89	11
Field et al[153]	2004	2-4	223	198	89	85-93	11
Peters et al[154]	2004	2-4	263	229	87	82-90	12
Chu et al[155]	2005	2-4	85	68	80	71-87	11
Gagliani et al[156]	2006	2-4	122	110	90	84-94	10
Gesi et al[157]	2006	2-4	256	238	93	90-96	12
	Pooled Success Rate (95% CI)				90 (88-92)		
	Weighted Success Rate (95% CI)				89 (88-91)		
Weiger et al[158]	2000	4-6	73	69	94	87-97	13
Friedman et al[159]	2003	4-6	405	393	97	95-98	12
Farzaneh et al[160]	2004	4-6	122	115	94	89-97	13
Marquis et al[161]	2006	4-6	132	114	86	79-90	11
	Pooled Success Rate (95% CI)				93 (87-97)		
	Weighted Success Rate (95% CI)				94 (92-96)		
Stoll et al[162]	2005	6+	595	506	85	82-88	10
Doyle et al[163]	2006	6+	196	161	82	76-97	9
	Pooled Success Rate (95% CI)				84 (82-87)		
	Weighted Success Rate (95% CI)				84 (81-87)		
RCT SURVIVAL Authors	**Year Published**	**Time in Years**	**Sample Size**	**Number Surviving**	**Survival Rate in %**	**Wilson Score Interval**	**Quality Score**
Lazarski MP et al[164]	2001	2-4	44,613	41,936	94	94-95	11
Waltimo et al[165]	2001	4-6	204	194	95	91-97	11
Alley et al[166]	2004	4-6	350	326	93	90-95	9
	Pooled Survival Rate (95% CI)				94 (92-96)		
	Weighted Survival Rate (95% CI)				94 (91-96)		
Aquilino and Kaplan[167]	2002	6+	129	115	89	83-93	10
Dammaschke et al[168]	2003	6+	190	162	85	79-89	11
Salehrabi and Rotstein[169]	2004	6+	1,462,936	1,419,048	97	97-97	9
Doyle et al[163]	2006	6+	196	184	94	90-96	9
	Pooled Survival Rate (95% CI)				92 (84-97)		
	Weighted Survival Rate (95% CI)				97 (97-97)		

Table IV. Evidence table for effects of tooth loss without replacement

Authors	Year	Field of Study	Study Type	Sample	Relevant Findings
Kayser[170]	1981	Oral function	Cross-sectional	118 patients	Four or more remaining pairs of occluding posterior teeth provided adequate oral function.
Witter et al[171]	1987	Tooth migration in shortened dental arches	Cross-sectional	132 patients	Tooth migration occurred in shortened dental arches, but within acceptable levels.
Oosterhaven et al[172]	1989	Perception of dental appearance, missing teeth	Cross-sectional	74 patients	Missing front teeth caused less positive feelings, more negative feelings, and strongly affected daily life activities.
Witter et al[173]	1990	Oral comfort in shortened dental arches	Cross-sectional	171 patients	Few patients with shortened dental arches reported impaired masticatory or esthetic complaints.
Haugejordan et al[174]	1993	Adjustment to cope with dental life events	Cross-sectional	284 responses	Losing a tooth required a significant period of adjustment and was likened to “trouble with relatives” in severity.
Witter et al[175]	1994	Function and comfort in shortened dental arches	Longitudinal 6 years	107 patients	Shortened dental arches are not risk factors for craniomandibular dysfunction or oral discomfort.
Shugars et al[139]	1998	Survival of teeth adjacent to posterior spaces	Retrospective 6-14 years	569 spaces	Untreated bounded edentulous spaces rarely resulted in loss of adjacent teeth; FPD treatment slightly improved survival rates.
Shugars et al[176]	2000	Nonreplacement of missing posterior teeth	Retrospective 1-10 years	126 patients	Effects of a bounded edentulous space on movement and bone height of adjacent teeth were minimal.
Witter et al[177]	2001	Occlusal stability in shortened dental arches	Retrospective 9 years	146 patients	Shortened dental arches can provide long-term occlusal stability; changes were self-limiting.
Gragg et al[178]	2001	Tooth movement adjacent to posterior spaces	Retrospective 1-8 years	116 spaces	Space loss was less than 1 mm in the first year after extraction; movement after the first 2 years was minor.
Davis et al[179]	2001	Emotional effects of tooth loss in partially dentate	Cross-sectional	91 responses	Emotional effects of tooth loss were common; confidence, dietary choice, food enjoyment, and social activities were affected.
Aquilino et al[180]	2001	Survival of teeth adjacent to posterior spaces	Retrospective 10 years	317 patients	Teeth adjacent to spaces restored with FPDs had slightly higher 10-year survival estimates than those that remained untreated.
Sarita et al[181]	2003	Temporomandibular disorders in shortened dental arches	Cross-sectional	850 patients	Distinct from absence of posterior support, shortened dental arches did not provoke temporomandibular disorders.
Hattori et al[182]	2003	Joint and tooth loads in shortened dental arches	Laboratory	5 patients	No evidence that experimentally temporarily shortened dental arches caused overloading of joints and teeth.
Sarita et al[183]	2003	Masticatory ability in shortened dental arches	Cross-sectional	850 responses	Slightly or moderately shortened dental arches provided sufficient masticatory ability and few complaints.
Wolfart et al[184]	2005	Oral health life quality in shortened dental arches	Prospective 1 year	34 patients	Patients with shortened dental arches reported good dental treatment satisfaction and oral health related quality of life.

TABLE V. Evidence table for psychosocial effects of implant-supported single crowns, fixed partial denture, and root canal therapies

Authors	Year	Field of Study	Study Type	Sample	Relevant Findings
Barbakow et al[185]	1980	RCT; outcomes	Prospective 0-9 years	566 teeth	Vast majority of the teeth had some form of preoperative pain.
Wong and Lytle[186]	1991	RCT and oral surgery; anxiety comparison	Cross-sectional	349 responses	Anxiety scores classified RCT and oral surgery to high anxiety; experience of RCT reduced anxiety.
Ekfeldt[187]	1994	ISC; outcomes	Retrospective 14-55 months	77 patients 94 implants	Large majority of patients rated function and willingness to be treated again positively, smaller majority rated appearance and number of complications as highly; dentists ranked appearance lower. Complications were common.
Andersson[188]	1995	ISC; outcomes	Prospective 2-3 years	91 subjects 102 implants	Patients and dentists described all crowns as having good esthetics.
Lobb et al[189]	1996	RCT; patient perception of problems	Longitudinal 1 year	165 responses	Approximately 20% of patients reported problems, mostly pain and restorative, but most did not seek a response; extremely high willingness to repeat treatment, but pain and expense were deterrents.
Andersson et al[103]	1998	ISC; outcomes	Prospective 1-5 years	38 patients 38 implants	Two of 38 crowns were considered esthetically unsatisfactory by dentists, but the patients declined offers to remake crowns.
Peretz and Moshonov[190]	1998	RCT; pretreatment anxiety	Cross-sectional	98 patients	DAS scoring indicated that gender and educational level influenced anxiety, but that RCT experience and pain did not.
Stabholz and Peretz[191]	1999	RCT, crown, extraction, comparison	Cross-sectional	180 patients	DAS scoring indicated that gender influenced anxiety, but that procedure type did not.
Chang et al[192]	1999	ISC; comparison with natural teeth	Cross-sectional	20 patients 21 implants	Patients reported extremely high level of satisfaction with appearance using visual analogue scale.
Chang et al[193]	1999	ISC; esthetic outcomes	Longitudinal 5-89 months	29 patients 41 implants	Patients reported extremely high level of satisfaction with appearance using isual analogue scale, but clinician's satisfaction was lower.
Moberg et al[90]	1999	ISC; evaluation, patient satisfaction	Longitudinal 1 year	29 patients 30 implants	28 patients with surviving implants generally had extremely positive responses to satisfaction, hygiene, biting, speech, esthetics, orofacial pain, and willingness to undergo treatment again.
Wannfors and Smedberg[91]	1999	ISC; outcomes	Longitudinal 3 years	65 subjects 76 implants	Patients reported extremely high levels of satisfaction comfort, phonetics, and esthetics at baseline and 3-year follow up using a visual analogue scale; somewhat inconsistent with very high prosthetic complication rates.
Johnson and Persson[92]	2000	ISC; outcomes	Prospective 3 years	59 subjects 78 implants	Extremely high levels of patient satisfaction were reported over time; low levels of altered satisfaction were initially reported, but this largely resolved over time.
Gibbard and Zarb[78]	2002	ISC; evaluation, patient satisfaction	Prospective 5 years	24 subjects 30 implants	Patients were extremely satisfied with appearance, function, and willingness to recommend treatment to others, but somewhat less satisfied with cleansability and willingness to undergo treatment again as reported on a Likert scale.
Dugas et al[194]	2002	RCT; life quality and satisfaction	Cross-sectional	119 subjects 238 teeth	RCT had profoundly positive impact on quality of life, especially on pain and psychologic state; high degrees of satisfaction were found, cost caused the most dissatisfaction; more satisfaction was found with endodontists.

Table V. *continued* (2 of 2) Evidence table for psychosocial effects of implant-supported single crowns, fixed partial denture, and root canal therapies

Authors	Year	Field of Study	Study Type	Sample	Relevant Findings
Watkins et al[195]	2002	RCT; pain and unpleasantness	Cross-sectional	333 patients	Pain and unpleasantness experienced during RCT was less than anticipated. Age and gender differences were found.
Sonoyama et al[196]	2002	ISC and FPD; life quality comparison	Cross-sectional	44 responses	Quality of life scores were high and did not differ between implant and resin-bonded FPD treatments with respect to: mastication and oral pain, speech, swallowing, hygiene, esthetics, general physical function and psychological state.
Andersson et al[97]	2003	ISC; evaluation, patient satisfaction	Retrospective 2-5 years	34 subjects 42 implants	Patients reported high satisfaction levels for postsurgery information, care, mastication, pronunciation, with lower levels for pretreatment information and pain. Patients and professionals reported high esthetic satisfaction.
Vermylen et al[197]	2003	ISC; patient satisfaction and quality	Retrospective 3-89 months	48 patients 52 implants	Patients were positive about esthetics, phonetics, eating, and overall satisfaction; less so about hygiene and cost; more would recommend treatment to others than would have it again. Dentists rated ~1/4 of same crowns as unacceptable.
Schropp et al[198]	2004	ISC; patient experience	Prospective 16-18 months	41 subjects 41 implants	Patients were very/extremely satisfied about treatment, surgeries, crown making, adaptation, esthetics, chewing; some differences between early and delayed treatments were found; visual analog and categorical questionnaires were used.
Levin et al[86]	2005	ISC; outcomes, esthetics	Longitudinal 1-9 years	48 subjects 52 implants	Extremely high rates of surgical survival and success were not predictive of esthetic success, which was somewhat lower, mostly due to free gingival margin problems.
Pjetursson et al[114]	2005	ISC; patient satisfaction	Prospective 5-15 years	104 patients 214 implants	Patients were highly satisfied with appearance, masticatory comfort, speech, esthetics hygiene, cost, fulfillment of expectations, and willingness to repeat treatment and recommend treatment to others; visual analogue scale was used.
Udoye et al[199] 199	2005	RCT; anxiety; RCT and extraction comparison	Cross-sectional	40 patients	RCT, followed by extraction, recorded the highest DAS scores. DAS was influenced by age but not by gender.
Bragger et al[200]	2005	ISC and FPD; economic comparison	Retrospective	89 patients 100 restorations	Implant treatment required more visits, but total treatment time was similar, and total cost (including laboratory, opportunity, and complication costs) was lower than for FPD treatment.
Szentpetery et al[201]	2005	FPD; patient reported problems	1-12 months	39 FPDs	Patients reported high incidence of wide variety of preoperative problems, but these resolved within 1 month of treatment, except for small proportion of food catching and smiling problems.

RCT studies had independent evaluators for 77% and 88% of the papers, respectively. Study durations varied, but most studies were of less than 6 years' duration (Tables I-III). The mean quality rating scores (and associated standard deviations), out of a possible total of 17 were: 7 (2) for papers describing ISC studies; 7 (3) for FPD studies; and 10 (2) for RCT studies. Thus, the available literature lacked many of the attributes desired for outcomes studies.

Sample size varied enormously from 28 to 1,462,936 (Tables I-III). Of the 24 RCT studies reviewed, 2 reported large sample sizes of 44,613 and 1.45 million subjects (Table III). The total number of participants was only reported in 87% of ISC studies, in 71% of FPD studies, and in 97% of RCT studies.

Clinical setting and provider type varied among treatment modes. Studies were coded as being conducted in teaching hospitals/dental schools (30%, 71%, 58%); private practice

(19%, 16%, 29%); or other/unknown (49%, 10%, 12%) for ISC, FPD, and RCT studies, respectively. A large majority of the studies (72% of ISC studies; 81% of FPD studies; 79% of RCT studies) reported results from a single center. Studies were coded as describing care provided by general practitioners and dental students (0%, 29%, and 63%); specialists (87%, 35%, and 29%); and unstated (13%, 29%, and 8%) for ISC, FPD, and RCT studies, respectively.

Patient demographics were incompletely described. Only 65% of the included studies noted patient gender. Within these studies, subjects were fairly evenly distributed between men and women, but women formed a small majority in all treatment modalities. Subject age was less frequently described, being reported in only 22% of the ISC studies, 16% of the FPD studies, and 32% of the RCT studies. The socioeconomic status of the participants was indicated in 21% of the RCT papers, but not in any ISC or FPD papers.

Outcome measures were most often crude and cumulative estimates of success or failure and of survival or loss. Success was defined in many different ways both within and among treatment modes; thus, its value was inherently limited.

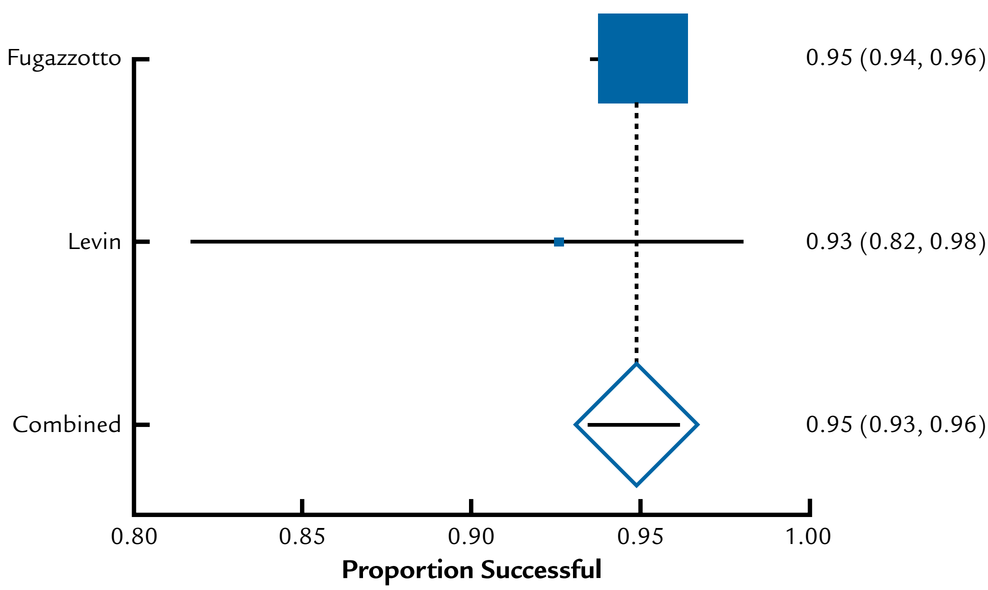
Methods of assessment were radiographic, clinical, and questionnaire, or combinations of these. Root canal treatment studies reported the most comprehensive outcome assessment, with 88% reporting the use of combined radiographic, clinical, and questionnaire evaluation. Most ISC studies, 77%, reported a combination of radiographic and clinical evaluation. Fixed partial denture studies reported the most varied methods of evaluation, with the most common being clinical, 35%; followed by radiographic and clinical, 29%.

Clinical outcomes

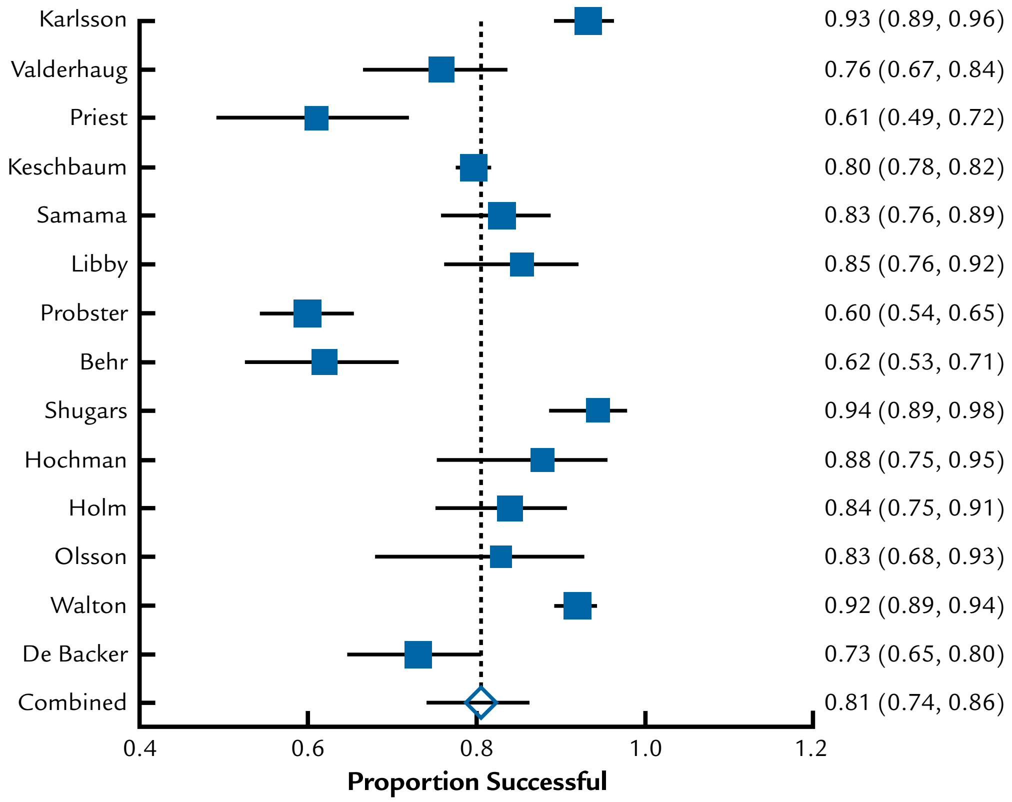
Clinical and/or biological outcomes in the evidence tables are expressed in the form of success and survival rates because data on harmful effects, beneficial effects, complications, and other biological effects were largely absent or inconsistently reported. Pooled and weighted success and survival rates for each follow-up period, with their associated 95% confidence intervals, are listed in Tables I to III. The Forest plots reflected the heterogeneity of the reviewed papers. Forest plots for 6+-year success and survival are displayed in Figures 6 through 10. Because 6+-year FPD survival was only represented by a single paper, a Forest plot was not made for this datum. A majority of the ISC papers provided survival rates. In contrast, a majority of the RCT studies and almost all of the FPD studies provided success rates. In most cases, pooled and weighted success and survival rates substantially overlapped. However, 1 of the 4 RCT 6+-year studies had a sample size of 1.45 million subjects (Table III) (Fig. 10). The pooled survival rate of these 4 studies was 92%, whereas their weighted average survival was 97%. Pertinently, pooled and weighted ISC survival means were both 97% for the same 6+-year time period (Table I) (Fig. 9). Substantial differences were also discerned between the pooled and weighted 4- to 6-year FPD success studies (Table II). Paradoxically, early ISC success rates were computed as being slightly higher than early ISC survival rates. Such differences reflect the methodological limitations of systematic reviews of heterogeneous literature.

Extraction without replacement

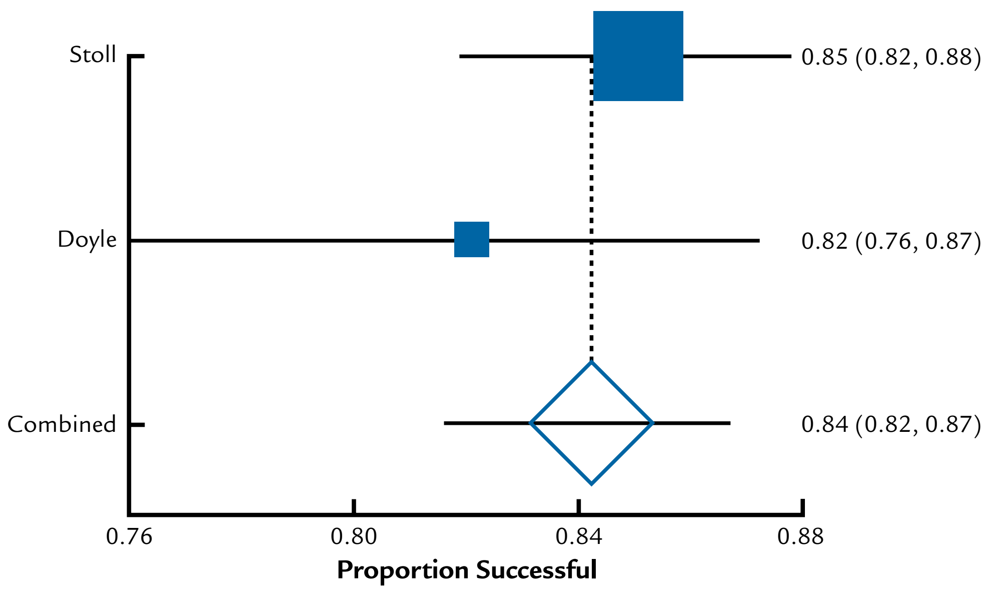
The impact of tooth extraction without replacement was primar-



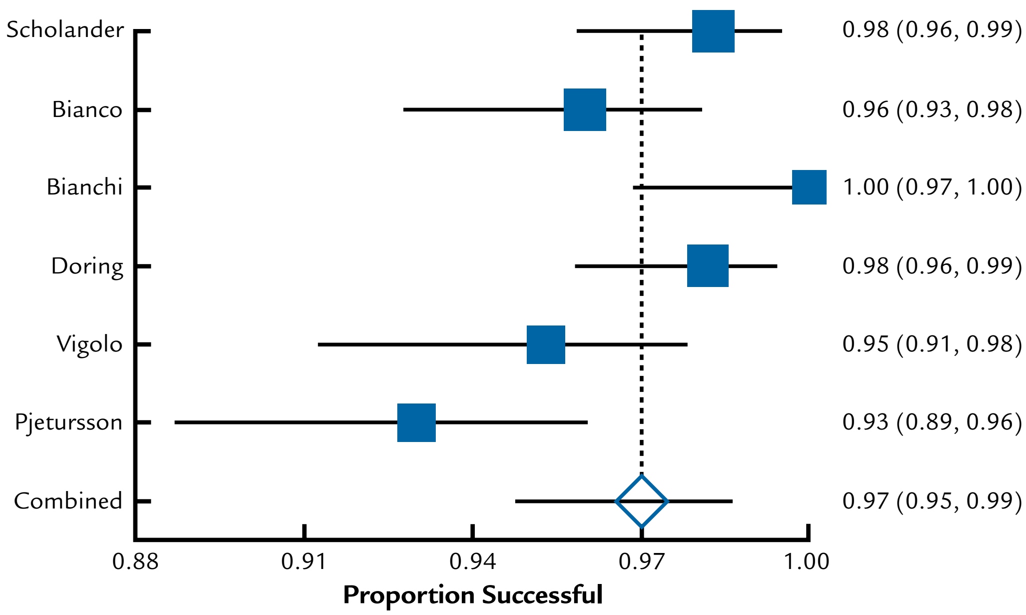
6 Forest plot of implant success at 6+ years; proportion meta-analysis plot, random effects model, with 95% confidence intervals in parentheses.



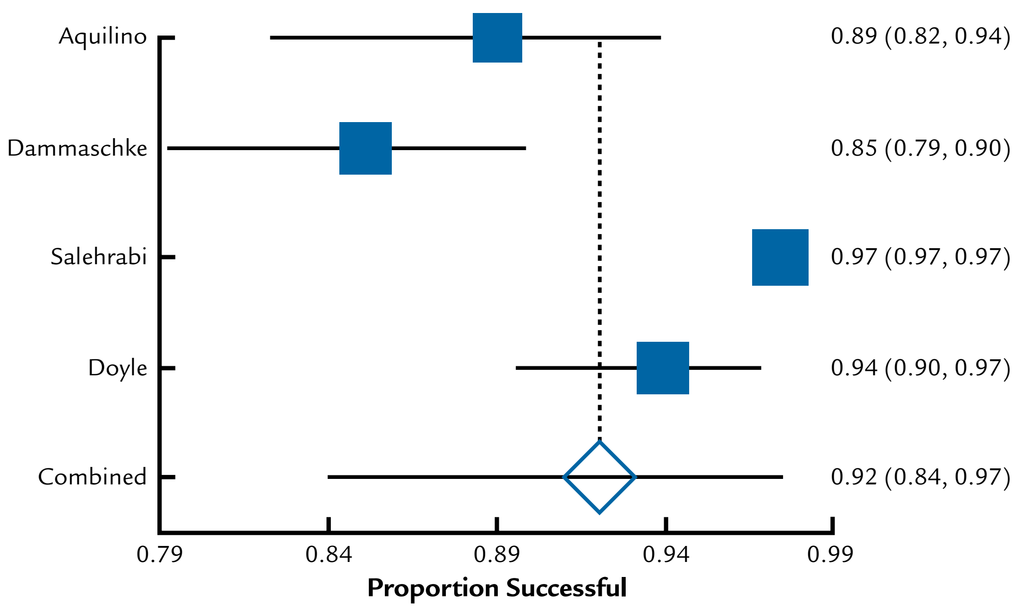
7 Forest plot of fixed partial denture success at 6+ years; proportion meta-analysis plot, random effects model, with 95% confidence intervals in parentheses.



8 Forest plot of endodontic success at 6+ years; proportion meta-analysis plot, random effects model, with 95% confidence intervals in parentheses.



9 Forest plot of implant survival at 6+ years; proportion meta-analysis plot, random effects model, with 95% confidence intervals in parentheses.



10 Forest plot of endodontic survival at 6+ years; proportion meta-analysis plot, random effects model, with 95% confidence intervals in parentheses.

ily described by the effects of shortened and interrupted dental arches and the impact of extraction on life quality (Table IV). This data was not systematically reviewable and necessitated narrative review. Moderately shortened dental arches had little, if any, impact on occlusal stability, tooth loading, temporomandibular disorders, interdental spacing, periodontal disease, patient comfort, or masticatory performance. Loss of a single posterior tooth, creating an interrupted dental arch or bounded posterior space, had remarkably little effect on shifting, decrease in alveolar support, or loss of adjacent teeth. Interestingly, provision of an FPD was associated with a modestly improved survival rate of adjacent teeth; however, a causal relationship was not established. Loss of visible teeth had momentous psychosocial impact.

Psychosocial outcomes

Psychosocial or quality of life effects of treatment tended to be reported in different ways among treatment disciplines. Direct comparison between different treatment modes was extremely rare. Masticatory performance and esthetics were commonly reported in the implant literature. Fixed partial denture patient-based outcomes were rarely reported, but a broad range of parameters and patient complaints were listed. Pretreatment anxiety and residual posttreatment pain were commonly addressed in the RCT literature.

A scant amount of FPD literature indicated that most patient complaints centered upon hygiene and functional problems such as food entrapment, sore jaws, and difficulty eating, but also included avoidance of going out in public and smiling. However, complaints were resolved at follow-up visits. A rare direct comparison between ISC and resin-bonded FPD treatment studied 7 parameters (mastication and oral pain, pronunciation, swallowing, oral cleansability, esthetics, physical function, and psychological state) and found no difference between those treatments (Table V).[10]

Studies of pretreatment anxiety of patients seeking nonsurgical RCT care were somewhat inconsistent; comparisons were most commonly made for patients seeking extraction. However, patients presenting to the dental office for extraction are often already in pain, as are those presenting for endodontic care. It was suggested that this may have raised the anxiety levels for both these patient populations. Women tended to demonstrate more pretreatment anxiety than men, but this difference decreased with patient age. Pain during RCT was usually less than anticipated and did not differ by gender.

Pain associated with treatment has been analyzed to some degree in the ISC literature, but not to the same extent as in the endodontic literature. A majority of patients reported implant treatment not to be painful. Those who experienced pain or unpleasantness rated it as being mild to moderate. Comfort during mastication was almost universal following implant restoration. The vast majority of RCT patients presented with preexisting pain; additionally, most also exhibited pain upon preoperative percussion testing. In the RCT literature, as represented in Table III, teeth with postoperative pain were generally assigned to failure categories. Clinical RCT outcomes instruments often included the objective measurement of pain upon palpation and percussion, as well as the patient's subjective historical account of the presence or absence of pain during masticating or incising, but incorporated these findings into overall tooth ratings. Overwhelming reduction in pain followed RCT care. Comfort levels were extremely high, largely equivalent to those following ISC treatments. A small minority of patients reported lingering problems after RCT, the majority of which were pain-related. Esthetic outcomes were often examined in the ISC literature. Very high levels of patient satisfaction were reported in the implant literature. Although dentist levels of satisfaction were high, they were consistently lower than patient ratings.

Patient perceptions of ISC complications were rarely reported, but the vast majority of patients believed that the number of complications was acceptable, even when high frequencies of complications were recorded. Root canal treatment studies did not separately address complications. However, most RCT outcomes instruments measured patient, clinical, and radiographic consequences of complications and assigned overall tooth ratings accordingly.

Willingness to either undergo the treatment again or to recommend it to others may be a valid indicator of patient satisfaction. High percentages of ISC and RCT patients reported willingness to choose the same treatment again.

Overall subject satisfaction ratings for both implant and endodontic treatments were extremely high, generally above the 90th percentile. Interestingly, endodontic patients with postoperative symptoms still reported equally high levels of overall satisfaction. It was conjectured that this may be due to dramatic diminution of pain levels as well as to an understanding of the expected course of healing. Satisfaction was significantly better when endodontic treatment was provided by specialists, in situations with more severe initial disease, and when the patients had completed a high school education.

Limited psychosocial data suggested that in patients with periodontally sound teeth that have pulpal and/or periradicular pathosis, tooth retention through root canal therapy and restoration or tooth replacement with an implant-supported single crown or a fixed partial denture resulted in superior quality of life outcomes compared to extraction without replacement.

Economic outcomes

Economic outcome data addressing the purpose of this study was largely absent. Some quality of life studies indicated that cost was a barrier to RCT; however, the vast majority of patients believed that both RCT and ISC costs were justified or that the cost-benefit was positive (Table V).[39,40,114,197] A short-term study comparing economic aspects of single tooth replacement by ISCs and FPDs in Switzerland found that implant patients required more office visits, but total time spent by the dentist was similar, and that the duration of the treatment, from beginning to end, was longer for the ISC patients (Table V).[11] However, the ISC demonstrated a superior cost-effectiveness ratio; the higher FPD lab fees outweighed the implant component costs. Time to function was shorter for RCT than ISC patients (Table V).[12]

DISCUSSION

Key findings and their limitations

The goal of this systematic review was to answer 3 clinical questions regarding initial nonsurgical endodontic care compared to extraction and placement of implant, fixed partial denture, or extraction without tooth replacement. These questions are important for the stakeholders in the dental health care system (patients, purchasers, brokers, unions, third-party payers, and dentists) who may have differing perspectives and expectations. Although the methods allowed for the broadest capture of the literature related to the questions, some articles may still have been missed, particularly those appearing in another language that were not subsequently reprinted in English. Consideration for inclusion of articles independently and then in group discussion helped to avoid the bias of single reviewer decisions. Participation of experienced statisticians helped to ensure proper article classification and appropriate data placement in the table of evidence.

The evidence identified by the authors did not permit them to definitively answer all of the questions posed. The studies demonstrated substantial variability in composition (study design, sample size, clinical setting and provider type, patient demographics), types of treatment procedures, and evaluation criteria among and within disciplines. Also, virtually no direct comparisons of one treatment with another have been reported. Hence, the evidence available for answering the questions came from indirect comparisons, that is, comparing the reported success and survival rates from 1 group of studies for 1 type of treatment with those from another group of studies for another type of treatment. For this reason, the conclusions must remain tentative, and there is a clear need for additional studies that ideally randomize assignment to alternative treatments, or at least conduct comparison of the treatments using standardized methods and measures.

Given these critical qualifications, the data demonstrated that in patients with periodontally sound teeth that have pulpal and/or periradicular pathosis, implant and root canal treatments had superior 6+-year weighted survival compared to replacement using fixed partial dentures. It also appears that both pooled and weighted (factoring in sample sizes) success rates consistently were higher for implant therapy than for endodontic treatment, which in turn were better than for fixed partial denture treatment. Additionally, root canal, implant-supported single crown, and fixed partial denture treatments had superior psychosocial outcomes, primarily with respect to patient self-image, compared to extraction without replacement.

Clinical outcomes, literature quality, and bias

The mean quality rating scores, out of a possible total of 17, were: 7 for papers describing ISC and FPD studies, and 10 for RCT studies. Thus, the literature generally lacked the methodological quality commonly accepted as being indicative of the best practices in study design and conduct.[33]

The implant discipline produced the highest number of usable papers in the shortest time (46 papers in 13 years), followed by fixed partial dentures (31 papers in 22 years), and by root canal treatments (24 papers in 27 years). This may reflect historical differences among the maturities of these disciplines. However, the older endodontic literature recorded the highest overall quality rating and included the most high-level studies. Changes in treatments that have occurred over time may have introduced biases favoring the discipline with the most recent papers. Conversely, the discipline currently undergoing the most rapid evolution may be disfavored, because recent changes may take some years before being reflected in the outcomes literature. The type of clinical provider created a bias. Implant treatment was largely provided by specialists; whereas, RCT was largely provided by generalists or students.

The inclusion criteria may have led to unintended selection biases. For example, only threaded implants were included. Thus, macro-scale smooth surface implants were excluded and studies on threaded implants using the Albrektsson et al criteria and its derivatives dominated.[41] Only studies that reported RCT results in terms of teeth, not roots, were included. Hence, many otherwise useful studies were excluded. Reporting RCT outcomes in terms of individual roots may have had more relevance in the past when apical surgery of the affected root was the predominant treatment for failed RCT. However, the currently accepted modality is nonsurgical retreatment of the entire tooth. In any case, from a patient's perspective, a single painful root indicates treatment failure for a tooth. Other biases and confounding effects may have manifested.

Clinical outcomes, success or survival

Success criteria used in implant studies varied.[14] The most frequently used criteria were those developed by Albrektsson et al,[41] and a simple measurement of periimplant annual marginal bone loss. Closely related criteria were also often used.[42-45] The original Albrektsson criteria included absence of mobility, absence of periimplant radiolucency, absence of signs and symptoms, low rates of vertical bone loss, and high 5- and 10-year success rates; minor modifications of these criteria are often made. The Albrektsson criteria were developed at a time when it was important to distinguish the biological outcomes of osseointegrated implants from those of their predecessors; thus, restorative and patient-based parameters received less attention. Later criteria added esthetic parameters.[42] Criteria developed by Buser[46] were infrequently used. Some studies used probing depth and bleeding on probing, whereas others have not.[47] Although the absence of pathology or inflammation is common to most success criteria, studies did not include the specific parameters historically reported in the periodontal literature. Evaluation of these parameters may become more widespread within the implant literature. Interestingly, the year of publication appeared unrelated to the choice of success criteria. The measurement of annual marginal bone loss was a common thread among the included literature. It has been suggested that implant success criteria are not routinely applied in much of the implant outcomes literature.[14] Carr[48] has argued that future implant success criteria must include multiple outcome domains, including consideration of the prosthesis, so that measured implant outcomes will have tangible meaning for patients.

Success and even survival criteria have not always been clearly defined in FPD studies (Table II).[49] Terms such as clinical retention rate and life span have been used instead of survival; the methods for calculating these outcomes have not always been reported clearly. Success has been described as complete survival or as functional survival. Failures have been designated as being biologic, technical, or patient-related; as being necessitated by remedial treatment or by a remake; as having reversible or irreversible complications; and as being primary or secondary. In an effort to allow comparison with previous research, some authors have used prior classification systems. However, the CDA/USPHS classification system was rarely used.[50] Most authors documented complications such as caries, need for endodontic treatment, and loss of retention, esthetics, periodontal disease, tooth fracture, prosthesis fracture, and porcelain veneer fracture. Resin-bonded FPDs were included due to the broad volume of available data and the viability of the treatment modality, particularly in the replacement of missing anterior teeth. Prosthesis debonding was a commonly described complication of resin-bonded prostheses. Interestingly, there appeared to be little difference in complication rates of resin-bonded and conventional fixed prostheses in this review.

Success, failure, and their intermediate stages have been described by many outcomes instruments in RCT studies, which often combine comprehensive clinical, radiographic, and anamnestic patient symptom components.[51] Endodontic outcomes measures were originally designed to enable the correlation of small differences in healing with prognostic indicators, not to describe patient-related clinical performance.[51,52] Unlike ISC and FPD therapies, RCT aims to cure existing disease. Thus, RCT studies measure both the healing of existing disease and the occurrence of new disease.[53] Hence, many RCT studies report data in terms of multiple categories of outcomes spanning the healing process, in contrast to most ISC and FPD data, which is reported in terms of binary success or failure categories. Endodontic healing often takes several years to occur, which may account for the higher RCT success rates with medium-term follow-up times reported in Table III.

Due to these considerable differences in meanings of success among and within disciplines, it is probable that consideration of survival rates, with and without minor and major interventions, will permit less biased, albeit less informative, comparisons.[12,54-56]

Long-term 6+-year weighted survival data indicated that in patients with periodontally sound teeth having pulpal and/or periradicular pathosis, root canal therapy resulted in superior survival (97%) to extraction and replacement of the missing tooth with a fixed partial denture (82%), and resulted in equal outcomes to extraction and replacement of the missing tooth with an implant (97%) (Tables I to III). In contrast, 6+-year success data ranked implant therapy (95%) as being superior to endodontic treatment (84%), which in turn was ranked as being superior to fixed prosthodontic treatment (80%) (Tables I to III). However, differing meanings of success limit the value of these observations.

Clinical outcomes, direct comparisons

Few papers were identified that directly compared the outcome or benefits or harmful effects of initial nonsurgical RCT and those of extraction and placement of ISCs, FPDs, or extraction without tooth replacement. These difficulties paralleled those of recent systematic reviews by Salinas and Eckert[14] and by Iqbal and Kim.[15] Lack of comparative studies with similar criteria for assessment of the outcomes, beneficial and harmful effects, with comparable time intervals made it difficult to make realistic comparison among these treatment modalities.

Direct comparison was extremely rare; only 1 paper directly compared implant and RCT clinical outcomes.[12] That paper had a retrospective case control design; that is, without random assignment. Most implants had been placed and restored by specialists or specialty residents, whereas dental students, residents, or staff clinicians performed most RCTs. In this rare instance, follow-up time was started at restoration, not at implant placement; however, the authors did record complications that occurred before restoration. Interestingly, implant-supported crowns that necessitated further interventions due to the occurrence of complications or restorative problems were assigned to unsuccessful categories. Thus, the authors reported much lower success rates than generally described in the implant literature. The authors did not specify the types of implant and endodontic treatments used within the study; but later personally communicated that most implants were of the screw-vent type and that all endodontic treatments used conventional methods including lateral and vertical condensation (Walter Bowles, DDS, April 13, 2007, written personal communication). Because of lack of detailed information regarding the type of implants used in this retrospective study, this paper was excluded from the implant evidence table. The authors concluded that restored endodontically treated teeth and single implant-supported restorations had similar survival rates; however, the implant group showed longer time to function and a substantially higher incidence of postoperative complications requiring subsequent treatment intervention. Other rare comparisons found that ISCs and FPDs did not differ in their psychosocial impact, and that ISCs had a superior cost-effectiveness ratio to FPDs.[10,11]

A recent systematic review comparing the clinical outcomes of restored endodontically treated teeth with those of implant-supported restorations concluded that survival rates of restored endodontically treated teeth and single implants did not differ, and 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.[15] As in the current study, the authors reported slightly higher, but not statistically significantly so, long-term (6-year) survival rates for implants. Unlike this analysis, the authors included only endodontically treated teeth that were subsequently restored.

Another recent systematic review compared the clinical outcomes of tooth-supported restorations with those of implant-supported restorations.[14] Consistent with this study, the authors concluded that at 60 months, ISCs had a higher survival rate than those supported by FPDs; however, if resin-bonded FPDs were excluded, no difference was found. Unlike this study, resin-bonded FPDs had a significantly lower success rate than conventional FPDs. However, different studies were included and a different time period was reported. The authors reported that FPD success rates continued to drop steadily over time beyond 60 months.

Insofar as comparisons can be made, the results of this broad systematic review were in general agreement with other prior, more narrowly focused systematic reviews on implant, fixed partial denture, and endodontic success and survival rates.[49,55,57-63]

After the cut-off date for inclusion in this systematic review, another large endodontic survival study was published.[64] That study reported a 5-year endodontic survival rate of 93% for a sample of 1.56 million teeth in a Taiwanese population. Had this study been included in the current analysis, both pooled and weighted 4- to 6-year survival rates would have been decreased slightly, but not below the 95% confidence limits reported in Table III.

The superior long-term survival rates of endodontic therapy suggest that this treatment should be given priority in treatment planning for periodontally sound single teeth with pulpal and or periradicular pathology (Tables I to III) (Figs. 9 and 10). The superior long-term survival rates of single tooth implants suggest that this treatment should be given priority in treatment planning for teeth that are planned for extraction. However, the many shortcomings of the available literature limit the strength of such a sweeping recommendation. Furthermore, treatment plans must be based upon the individual patient's situation.

Clearly, more data, especially from prospective controlled clinical trials, is needed to answer to questions such as: "Under what circumstances should a tooth be retained through RCT and restoration, or should it be extracted and replaced by an implant-supported crown or by a fixed partial denture?" In a recent publication, Doyle et al[13] retrospectively examined factors affecting outcomes for single-tooth implants and endodontically treated teeth restorations. The authors reported that both therapies are affected by smoking, but not by diabetes, age, or gender. RCT outcomes were affected by the presence of periradicular periodontitis, post and core placement, and overfilling, but not by the number of appointments. Within limits, implant outcomes were not affected by implant length, diameter, or the presence of an adjacent endodontically treated tooth. Long-term prospective data on large sample sizes is needed.

Clinical outcomes, complications

Treatment complications were dealt with differently among the treatment modes adddressed within this study. In the implant studies, evaluation of complications other than implant loss was generally limited.[41] Several of the fixed prosthodontic studies provided data on common complications (Table II). In contrast, most endodontic studies assigned teeth with clinical, radiographic, or patient-related signs or symptoms of complications to failure categories (Table III). Other reviews have reported high incidences of implant complications.[55,65] One of these reviews adopted a narrative approach due to the inherent limitations of the literature[65]; the other applied a systematic approach, but only 4 studies could be included.[55] Complication rates may have been overestimated in these reviews.[66] Additionally, recent advances may have subsequently reduced the incidence of complications; for example, increased use of cemented abutments and torque devices may have already decreased the incidence of screw loosening. However, several of the studies listed in Table V described extreme ISC complication rates; 1 reported a 3-year complication rate of 92%.[67] Likewise, high rates of FPD complications have been reported.[68] It appeared that complications rarely necessitated loss of an implant, loss of an FPD, or loss of an endodontically treated tooth, but frequently required additional intervention. Assignment of complications to categories requiring major and minor interventions would be a reasonable way to uniformly address different types of complications among different disciplines in a clinically relevant manner.[12] Different temporal failure and complication patterns may affect different treatment modes in different ways.[6,12,14,65,68] For example, early loss rates of osseointegrated implants may be considerably higher than later loss rates. Conversely, retained teeth may be more susceptible to late failure due to the effects of coronal leakage or microbial ingress, caries, and periodontal disease.

Psychosocial outcomes

Limited psychosocial data was identified in this systematic review (Tables IV and V); this was summarized within the previously mentioned results. However, psychosocial or life quality effects are likely critical to patients. Esthetic and comfort-related questions might be particularly important. The study of the psychosocial effects of single tooth loss, retention, or replacement is in its infancy. Although few psychosocial studies were identified, strong trends were evident.

Limited psychosocial data suggested that tooth retention through root canal therapy and restoration or tooth replacement with an implant or a fixed partial denture results in superior clinical outcomes, compared to extraction without replacement. The reasons for this were due to diminution of esthetics and psychological trauma associated with tooth loss, such as self-image, not physiological function.

Biological outcomes

Remarkably little data focusing upon biological outcomes, and their benefits or harmful effects, such as inflammation, infection, and caries activity, were identified. However, measures of their surrogates, such as radiographic signs of bone loss, or pain on masticating, were often included within clinical outcomes instruments. Biological outcomes, benefits, and harmful effects have been noted within the literature, but less frequently measured or compared.

Benefits and harms

Benefits and harms were rarely distinguished from overall survival and success data (Tables I-III). Some benefit and harm data was described within the single tooth extraction without replacement and psychosocial results sections (Tables IV and V). Other benefits and harms were not directly captured by this systematic review, but are largely self-evident.

The principal benefits of extraction are pain relief and removal of diseased tissues. The principal harmful effect of single tooth extraction without replacement is its tremendous impact on patient's perceptions of themselves (Table IV). Physiological effects appear to be relatively minor (Table IV), but surgical complications and sequellae may be encountered.

Benefits of retaining a tooth by treatment of pulpal and/or periradicular pathosis and restoration may include conservation of the remaining crown and root structure, preservation of alveolar bone and accompanying papillae, preservation of pressure perception, and lack of movement of the surrounding teeth. Conversely, a retained tooth may be at risk for future root fracture and development of caries or periodontal disease.

The primary benefits of replacement of a missing tooth with a fixed partial denture may be patient self-image and esthetics, with minor physiologic gains (Tables IV and V). Tooth preparation and subsequent provision of fixed partial dentures are widely considered to increase the future risk of pulpal, periradicular, and periodontal diseases. Likewise, the primary benefits of replacement of a missing tooth with a fixed partial denture may be self-image and esthetics, with minor physiologic gains (Tables IV and V). Unlike fixed partial denture treatment, implant treatment does not involve preparation and restoration of adjacent teeth and the attendant risks. Implant placement may help to prevent bone resorption after extraction. All means of tooth replacement may face esthetic challenges in recreating natural hard and soft tissue contour and appearance. Benefits and harms may take decades to manifest, but most of the studies in this systematic review were of 6 or fewer years in duration.

Economic outcomes

Only minimal economic data was identified within this systematic review. Evidence-based studies of comparative survival rates should include an economic assessment of outcomes. Economic outcomes are generally described by cost-effectiveness (C/E) and cost-benefit (B/C) ratio analyses. These techniques have been applied in health care both to evaluate competing programs, such as prevention of disease versus its treatment, and to evaluate competing therapies for similar health conditions, such as the treatment of coronary artery disease as a sequela of atherosclerosis.[18-22] Different perspectives can be used to conduct C/E and C/B analyses; studies can be approached from the point of view of the providers or from the point of view of the consumers. The most general approach is from the perspective of society as a whole. With this approach, the total benefits and total costs from all sources and all participants are counted in the evaluation of alternative therapies.

Cost-effectiveness is the simpler approach because it holds the outcome constant. For a given outcome, for instance, removal of disease and restoration of maximum attainable function to the dentition, costs of alternatives are compared. As long as the outcome (benefit) is the same for all alternative therapies, the approach is essentially a cost comparison; the least-cost alternative being preferred. This C/E approach estimates the relative efficiency of the alternatives. The therapy that requires fewer resources as measured by clinician time and training, and cost of materials, is more efficient in conserving resources. Economic costs may be borne by patients, dentists, third parties, or by society.

Initial costs, in US dollars, of each

of the 4 treatment alternatives can be calculated using the national fee averages collected by the American Dental Association through its Services Rendered Survey to yield national and subnational estimates of fees for general practitioners (GPs) and specialists for each CDT4 code (The American Dental Association's Code on Dental Procedures and Nomenclature). Although this survey contains proprietary information, and lacks of journal review board peer-review, these factors do not negate its value with respect to systematic review of the best available evidence. These data have been used to illustrate the conduct of a simple cost-benefit analysis below. These fees were only the initial costs of the therapies at the time this paper went to press; whereas, lifetime costs are more meaningful. The initial costs of a simple extraction, provided by a general practitioner or an oral surgeon, are $101 and $123, respectively. The initial cost of an extraction, endosteal implant, abutment, and crown is approximately $2850 and does not vary substantially whether a general dentist, an oral surgeon, or a periodontist provides the surgical care. The initial costs of an extraction followed by a 3-unit FPD using a high noble metal-ceramic restoration differs considerably, depending on whether general dentists or prosthodontists provide the FPD, and are $2300 and $3300, respectively. The costs of an anterior RCT provided by a general dentist with a composite resin restoration, and a molar RCT provided by an endodontist followed by an amalgam foundation and a high noble metal-ceramic crown, are approximately $743 and $1765, respectively. These 2 examples of RCT and restoration were chosen so as to bracket the cost range. This simple analysis does not include consultation fees; preoperative radiographs, which may vary from simple periapical views to cone-beam tomography and CT; or additional, separately charged procedures such as surgical guides or some types of provisional restorations. Clearly, initial costs were lowest for the extraction-only option. Among the remaining 3 options, RCT is the lowest. The cost ranges of the ISC and FPD therapies overlapped. However, these are just initial costs, not lifetime costs, and as for all comparisons made within this review, a sound periodontium was assumed.

The assumption of comparable outcomes with C/E analysis is an inherent shortcoming. Of the 4 therapies being compared in this review, 3 options result in the loss of a natural tooth. Only 1 alternative preserves the natural tooth and its sound periodontium. Since the outcomes are not identical, B/E is the appropriate approach to comparison of alternative therapies. However, this approach entails more than simply comparing total costs and choosing the service that costs the least. Instead, benefit, or value to the patient, must be defined and measured. Relative treatment longevity is an important dimension of C/B evaluations; lifetime C/B comparisons are more meaningful than time to the next treatment. Limited evidence suggests that long-term complication rates differ substantially among the therapeutic choices addressed in this systematic review and that retention with endodontic therapy may have lower complication rates.[12,65,68]

Benefits of health care usually include removal of existing pathology, prevention of future or recurrent pathology, restoration of function, absence of discomfort or pain, esthetics, and psychological acceptance of the services by the patient. If the service is delivered within a market (voluntary exchange between the patient and the health professional), and the patient is well informed (can evaluate the various aspects of benefits), market prices should provide a fairly accurate indication and the relative cost/benefit of the 4 alternatives. However, most observers question whether or not patients can make a C/B evaluation of such a technical nature regarding individually produced services, especially since a consensus has not emerged regarding C/B of the alternative services within the dental profession. This systematic review of the existing literature demonstrated that studies specifically designed to assess the cost-benefit of the 4 alternative services are almost completely absent.

Nevertheless, the parameters for an evidence-based C/B comparison of these alternatives are well understood. Since root canal therapy retains a natural tooth, most will recognize this as a benefit that the other 3 therapies do not provide. Of course, the natural tooth must not have residual pathology of clinical significance, must fulfill its function within the dentition, not be a source of discomfort for the patient, and have acceptable esthetics. If these requirements are met by retention, then choice of another alternative on a C/B basis must provide greater functionality, less discomfort, or better esthetics than root canal therapy. Again, one can again start with a reasonable assumption: it is better to preserve natural dentition than to lose natural teeth even if replaced by an implant or prosthesis. Consequently, the burden of proof lies with the alternatives to root canal therapy. It needs to be demonstrated that 1 of these alternatives results in less total lifetime costs or provides greater lifetime function, freedom from pathology, comfort, or acceptability to a patient. Currently, such data is unavailable. Although economic data is largely absent, retention of a periodontally sound tooth clearly has tremendous cost-benefit and cost-effectiveness in comparison to any alternative where the tooth is lost.

CONCLUSIONS

The existing literatures describing outcomes of using root canal therapy, extraction without replacement, extraction with replacement using a fixed partial denture, and extraction with replacement using an implant, is problematic. Comparative studies were absent, success was defined in very different ways both within and among the different treatment modes, complications were largely undescribed, and psychosocial outcomes were incompletely addressed. For these reasons, the questions addressed in this review must be answered only tentatively, and with reference only to 2 outcomes.

Based on available evidence it appears that initial endodontic treatment has high long-term survival rate for periodontally sound teeth that have pulpal and/or periapical pathosis. Equivalent long-term survival rates have been also reported for extraction and replacement of the missing tooth with an implant-supported restoration. Substantially lower long-term survival rates have been reported for extraction and replacement of the missing tooth with fixed partial dentures.

For patients with periodontally sound teeth that have pulpal and/or periradicular pathosis, implant, endodontic, and fixed prosthodontic treatments had superior psychosocial outcomes, primarily with respect to patient self-image, compared to extraction without replacement or with replacement using a fixed partial denture. Prospective large individual or multicenter clinical trials with clearly defined clinical criteria for survival, with and without intervention; patient life quality information; and economic outcomes are needed to compare alternative treatments. High-level studies will require expertise, time, and economical support from the various stakeholders.

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Corresponding author:
Dr Shane N. White
UCLA School of Dentistry
10833 LeConte Ave
CHS 23-010
Los Angeles, CA 90095-1668
Fax: 310-206-3644
E-mail: snwhite@dentistry.ucla.edu

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Noteworthy Abstracts of the Current Literature

Repeated distraction osteogenesis for excessive vertical alveolar augmentation: a case report

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In this article, a procedure involving 2-stage alveolar distraction osteogenesis using eccentric distraction devices for the augmentation of resorbed transplanted iliac bone following mandibular tumor resection is presented. A 6-month consolidation period was allowed between the first and second distractions, and endosseous implants were placed 4 months after the second distraction. Computerized tomographic images obtained before the implantation revealed that, 10 months after the first distraction, the bone generated still showed lower density compared with the basal bone, but the bone from both distractions showed enough maturity for implantation. It may be concluded that 2-stage alveolar distraction osteogenesis can be a useful and safe procedure for excessive alveolar lengthening if a sufficiently long consolidation period is allowed.