

# In Patients Requiring Single-Tooth Replacement, What Are the Outcomes of Implant- as Compared to Tooth-Supported Restorations?

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**Purpose:** The study provides a systematic review of the literature to determine the long-term survival characteristics of single implant-supported crowns and fixed partial dentures. **Materials and Methods:** A search of the MEDLINE, EMBASE, and Cochrane Collaboration databases was conducted to identify articles that compared survival and success of fixed partial dentures and single implant-supported crowns. In addition to comparative cohort studies, articles that pertained specifically to single implant-supported crowns or fixed partial dentures were included in this review. Inclusion criteria for implant and fixed partial denture articles included a minimum 2-year study, primary publication in the English language, a minimum of 12 implants, implants designed to osseointegrate, and inclusion of data regarding implant and prosthetic performance. Data were analyzed using cumulative proportions of survival and success for both prosthetic types and for individual implants. Wilson score method was used to establish 95% confidence intervals for each population. The chi-square test for homogeneity was performed. **Results:** The literature search failed to identify any articles that directly compared survival or success of single implant-supported restorations with fixed partial dentures. Following the search criteria, and independent analysis by reviewers, 51 articles were identified in the implant literature (agreement, 95.42%; kappa coefficient, 0.8976), and 41 were identified in the fixed partial denture literature (agreement, 90.97%; kappa coefficient, 0.7524). Pooled success of single-implant restorations at 60 months was 95.1% (CI: 92.2%–98.0%), while fixed partial dentures of all designs exhibited an 84.0% success rate (CI: 79.1%–88.9%). **Conclusions:** This systematic review of the scientific literature failed to demonstrate any direct comparative studies assessing clinical performance of single implant-supported crowns and tooth-supported fixed partial dentures. The analysis suggested differences at 60 months between survival of implant-supported single crowns and natural tooth-supported fixed prostheses when resin-bonded and conventionally retained fixed prostheses were grouped. This difference disappeared when implant-supported single crowns were compared with conventionally retained fixed partial dentures at 60 months. For other time periods, direct comparative data were unavailable. *INT J ORAL MAXILLOFAC IMPLANTS* 2007;22(SUPPL):71–95.

**Key words:** etched bonded dentures, fixed partial dentures, implant-supported restorations, implant-supported single crowns, implant-supported single-tooth restorations, resin-bonded fixed partial denture, success, survival

Patients with missing teeth face the prospect of tooth replacement either through the use of removable prostheses, fixed natural tooth-supported prostheses,

or implant-supported prostheses. Each of these prosthetic designs has inherent risks and benefits.

Although it is possible to replace single teeth using a removable partial denture, these restorations are generally considered provisional in nature rather than definitive. For this reason, removable partial dentures were not considered in this review. In distinction, fixed natural tooth-supported prostheses (FPDs) and implant-supported single crowns (ISCs) may be more applicable to the restoration of the single missing tooth. When considering either of these treatment options, the clinician must weigh the risks and benefits of either approach. Careful scrutiny of the scientific lit-

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erature may assist the clinician in determining the treatment when a single-tooth replacement is needed.

Previous systematic reviews of implant-supported single restorations demonstrated that failure of osseointegrated implants occurred relatively early in the period of follow-up.<sup>1,2</sup> The prosthetic complications of ISCs, however, seemed to be infrequent and easily correctable in comparison with other types of implant-supported or retained restorations such as overdentures or fixed partial dentures.<sup>3</sup>

Previous systematic reviews of fixed tooth-supported partial dentures demonstrated both biologic and structural complications occurring relatively long after initial prosthesis insertion.<sup>4-6</sup> In meta-analyses of resin-bonded FPD (RBFDP) studies, it is apparent that these restorations have therapeutic advantages in the short term.<sup>7</sup> It was of interest to the authors and the sponsorship by the Academy of Osseointegration to include a representative population of RBFDPs and fixed partial dentures and restorations for survey of survival characteristics.

The purpose of this study was to conduct a systematic review of the scientific literature to assess the success and/or survival of ISCs in comparison to FPDs.

## MATERIALS AND METHODS

The dental literature was searched from 1966 to August 2004 using MEDLINE, Cochrane Collaboration, and EMBASE to determine a list of scientific articles pertaining to clinical use of dental implants and FPDs in humans. The 2 individuals also reviewed a master list of implant articles supplied by an advisory group of the Academy of Osseointegration to determine article applicability to the primary question using the established inclusion criteria. Each reviewer searched the references independently. When disagreement was found, the articles were discussed until agreement was reached. Calculations were made to determine percentage of reviewer agreement and the kappa coefficient. References from the identified articles were hand searched.

### Inclusion Criteria

The master lists were sorted to determine the presence of articles pertinent to single implant-supported restorations, FPDs, and RBFDPs. The list of articles that related to single implant-supported restorations was then reviewed through comprehensive assessment of each original article.

*Implant-supported Restorations.* Articles were included in the data extraction section of the systematic review if they demonstrated at least 2 years of clinical survival, included a minimum of 12 restora-

tions, had been first published in the English language, and presented data that could be extracted. Anticipation of attrition rates of 20% or more<sup>8</sup> resulted the decision to include studies with a minimum of 12 FPDs or single implants with restorations for review. Only studies that clearly differentiated ISCs from other prosthetic designs were included. Only clinical studies of adult subjects could be included. Animal studies, in vitro studies, technique articles, and case reports were all excluded from this review.

*FPDs.* Articles were included in the data extraction section of the systematic review if they demonstrated at least 2 years of clinical survival, included a minimum of 12 restorations, had been first published in the English language, and presented data that could be extracted.

### Data Extraction

Data were extracted from the references relative to implant survival, prosthesis survival, and method of failure as it applied to ISCs. Similarly, data were extracted from references relative to tooth survival, prosthesis survival, and mode of failure as applied to FPDs. Data were extracted relative to time; when time-dependent data were unavailable, articles were rejected from the review.

Data extraction tables were created to determine time of implant placement, time of prosthesis service, implant survival rate relative to time, and prosthetic complications relative to time. Surgical success (a term that can be used interchangeably with "survival" here) as well as prosthetic complications from each study were recorded. Data were extracted for all time periods in the original article. Data extraction from fixed prosthodontic literature was performed to determine prosthesis success and survival and prosthesis complications relative to time of service.

The data were analyzed by Howard Proskin and associates and are described in an article elsewhere in this issue. The data are depicted in forest plots with associated 95% confidence intervals. Data were surveyed by dichotomization to either the ISC or the FPD group. The level of influence by factoring RBFDPs out of this data set was also examined.

### Statistical Methods

All studies that reported cumulative proportional implant survival, implant success, or prosthetic success for at least 1 examination and at least 1 treatment were included in the analysis. The cumulative proportions were assumed to describe all implants in the treatment group. The last reported implant survival, implant success, and/or prosthetic success for each treatment from each article were used to derive

overall estimates of implant survival, implant success, and prosthetic success, respectively. In addition to finding overall estimates for each proportion, the meta-analysis was performed for different time-points. A pooled estimate of implant survival, implant success, and prosthetic success was derived for each timepoint as well as for the last examination.

Point estimates of implant survival, implant/tooth success, and prosthetic success from each article are depicted graphically in forest plots for each timepoint and overall. The Wilson score method was used to derive a 95% confidence interval for each proportion.<sup>9,10</sup>

A random-effects model was necessary for calculating the pooled estimates when there was heterogeneity between studies. According to the chi-square test for homogeneity, there was significant heterogeneity between studies in almost all cases.<sup>11</sup> A random-effects model was used even if homogeneity was not rejected at the 0.05 level, because there seemed to be heterogeneity between the studies. There were a few cases where a treatment group only included a single study or where all studies in a treatment group had 100% implant survival, implant success, or prosthetic success; in these cases, a fixed-effects model was used to derive the pooled estimate. The random-effects model was used in all other cases.

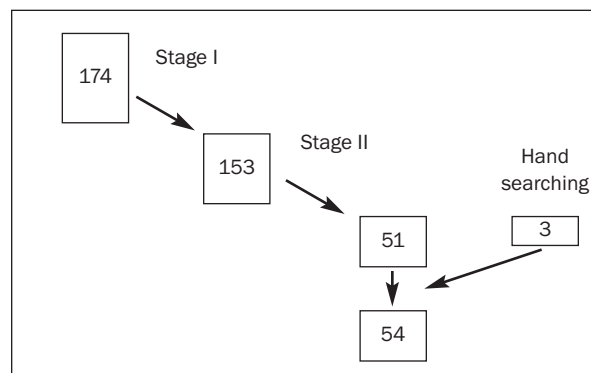
The method of generalized estimating equations was the use of the random-effects model to combine rates from individual studies.<sup>12</sup> This method accounted for the between-study variability. Pooled Wilson score confidence intervals (CIs) were used in the fixed-effects model. Estimates were computed using R. 2.2.1 (R Foundation for Statistical Computing, Vienna, Austria).

## RESULTS

A preliminary review of the scientific literature identified 1,766 articles that were included into a database. No direct comparative studies assessing the success or survival of ISCs and FPDs were identified through this literature review. Consequently, the original plan to perform a systematic review of 2 approaches to therapy was abandoned. Instead, the 2 treatment approaches were evaluated relative to prognosis. Few studies were identified with overlapping time periods for either FPDs or ISCs. Because there were no direct comparative studies, most results provided in this review are descriptive in nature.

### ISC Literature

A secondary search of the literature was combined with the master list; this produced 174 full-text arti-



**Fig 1** Application of inclusion/exclusion criteria to the literature on single-implant restorations.

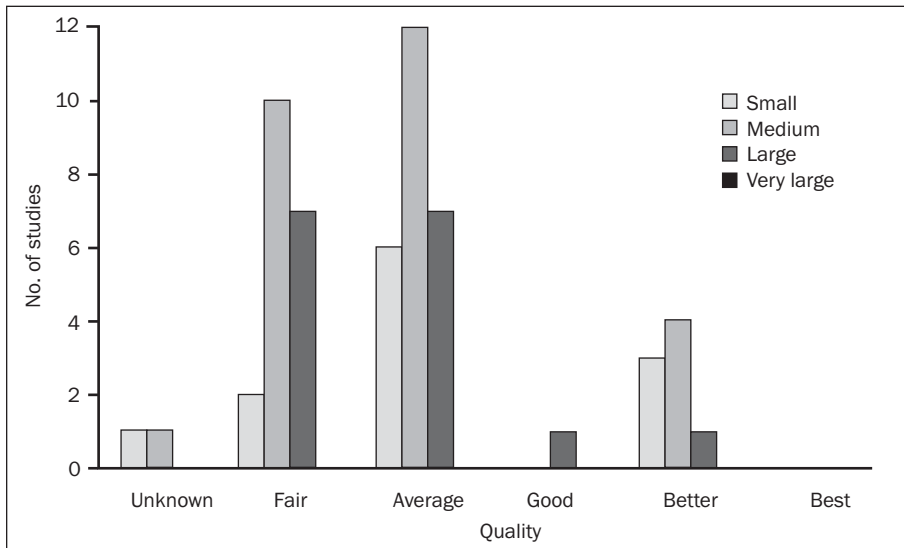
cles related to single-implant restorations for which abstracts were reviewed according to inclusion/exclusion criteria.<sup>1-3,13-183</sup> A total of 13 of these studies were excluded by both reviewers. An additional 8 studies were not agreed upon by the reviewers. Consequently, these articles were discussed and ultimately, 7 of the articles were excluded through this arbitration process (agreement, 95.95%; kappa coefficient, 0.7666). The second stage of manuscript review was initiated on the group of 153 articles. After this screening, 98 articles were agreeably eliminated by both authors based on inclusion criteria. An additional 7 articles were in dispute. Discussion and arbitration of these articles allowed inclusion of 3 (agreement, 95.42%; simple kappa coefficient, 0.8976). This created a total of 51 articles.\* After hand searching, an additional 3 articles were included (Figs 1 to 3).<sup>184-186</sup> No articles were added after the cutoff date of May 31, 2005 (see the ISC Inclusion List available in the Web edition of this article).

### FPD Literature

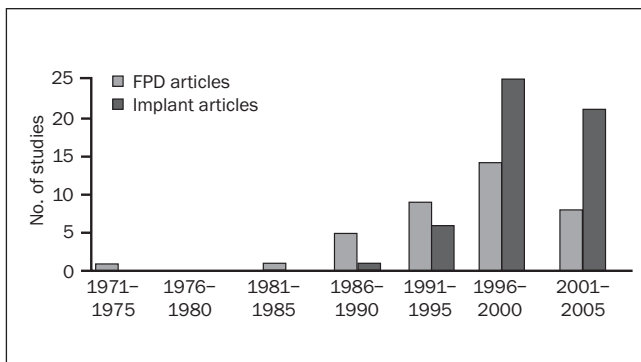
The fixed prosthodontic literature yielded an initial list of 265 article abstracts.<sup>1,4-7,44,45,117,132,164,187-447</sup> Five meta-analyses were also found.<sup>1,4-7</sup>

A stage I review was conducted and disclosed mutual acceptance of 156 manuscripts by each author. One hundred six manuscripts were agreeably negated by the 2 reviewers, and 3 additional articles were in dispute. These articles were discussed, resulting in the addition of 1 additional article for further review (agreement, 98.87%; kappa coefficient, 0.9765). A total of 155 full-text articles were agreed upon. At Stage II, 30 manuscripts were mutually accepted, 111

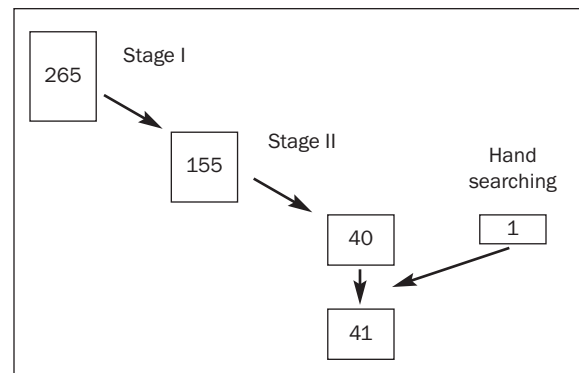
\* References: 16, 18-23, 25, 26, 30, 42, 52, 55, 57, 65, 70, 71, 74, 76, 78, 80, 84, 86-89, 92, 96, 104, 106, 109, 115, 116, 127, 131, 133, 134, 136, 138, 144-146, 150-153, 171, 172, 174, 175, 176



**Fig 2** Size and quality of implant studies.



**Fig 3** Article distribution by year.



**Fig 4** Application of inclusion/exclusion criteria to the literature on FPDs.

were mutually rejected, and 14 articles were in dispute. After discussion, it was agreed to accept 10 of the disputed articles and reject the remainder (agreement, 90.97%; kappa coefficient, 0.7524). Hand searching provided an additional article, resulting in 41 articles for data extraction (Figs 3 to 5; see the ISC Inclusion List available in the Web edition of this article).\*\*

**Characteristics of ISCs**

Although many authors described successful treatment, success criteria were rarely identified in articles. Consequently, results will be described relative to survival only. ISC articles were surveyed for survival information. Generally both surgical survival and prosthetic survival were described. Most frequently implant survival was described in terms of cumulative survival (Fig 6). Several studies<sup>26,30,70,152</sup>

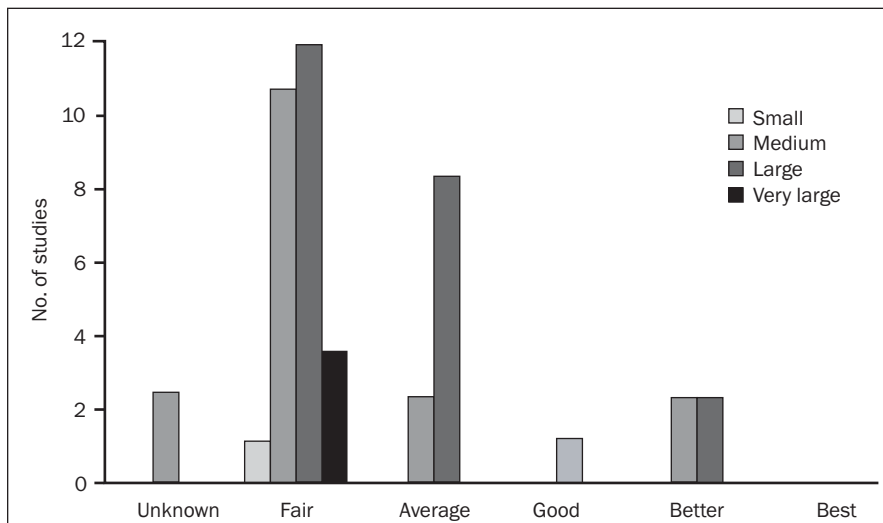
enrolled relatively large numbers of subjects (252 to 282); the survival proportions for these studies were proportional to those observed in most other studies. The implants placed in these 4 studies (n = 1,064) composed 36% of the entire implant population in this systematic review.

Early reports demonstrated higher numbers of prosthetic complications, including screw loosening and fracture. With the development of implants containing internal connections and other strategies for the partially dentate patient, abutment screw loosening and fractures were observed less frequently in more current literature. Implant prosthetic success was termed as the outcome of the implant prosthesis, assuming the implant remained integrated, while complications were described if a complication required intervention but not prosthesis refabrication. Figure 7 illustrates this level of prosthetic success at 60 months.

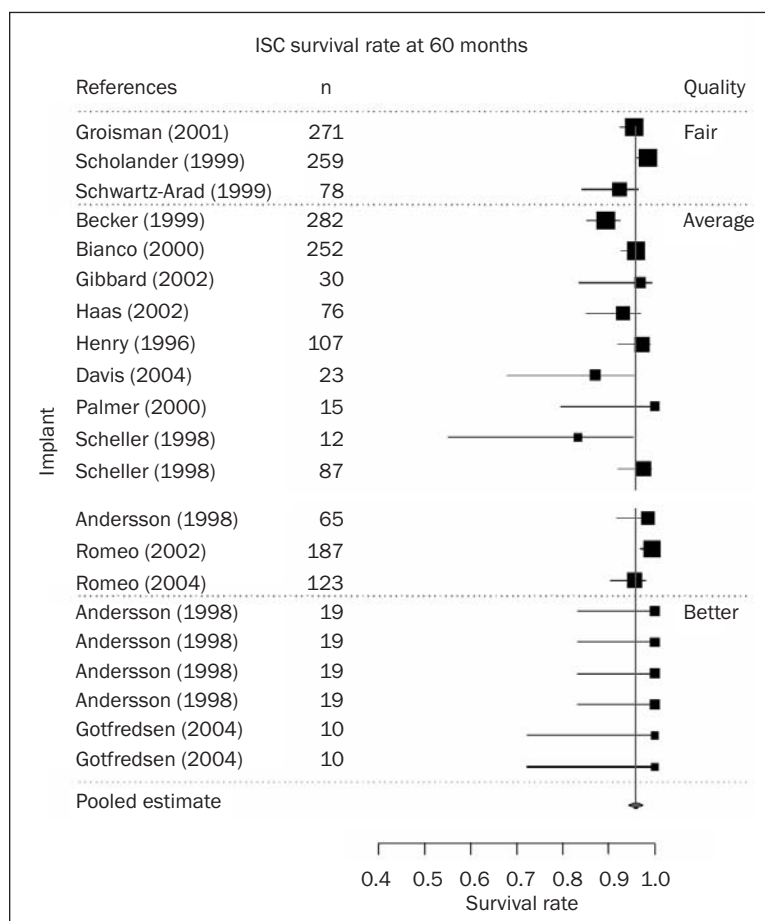
Immediate loading with a provisional restoration was assessed in 2 studies with favorable results, although the study numbers were low and the follow-up period short.

\*\* References: 191, 198, 200, 204, 209, 213, 231, 235, 237, 238, 247, 250, 260, 274, 278, 289, 293, 296, 299, 312, 318, 340, 343, 355, 366, 368, 375, 377, 378, 380, 382, 386, 390, 394, 397, 407, 416, 423, 429, 434, 446

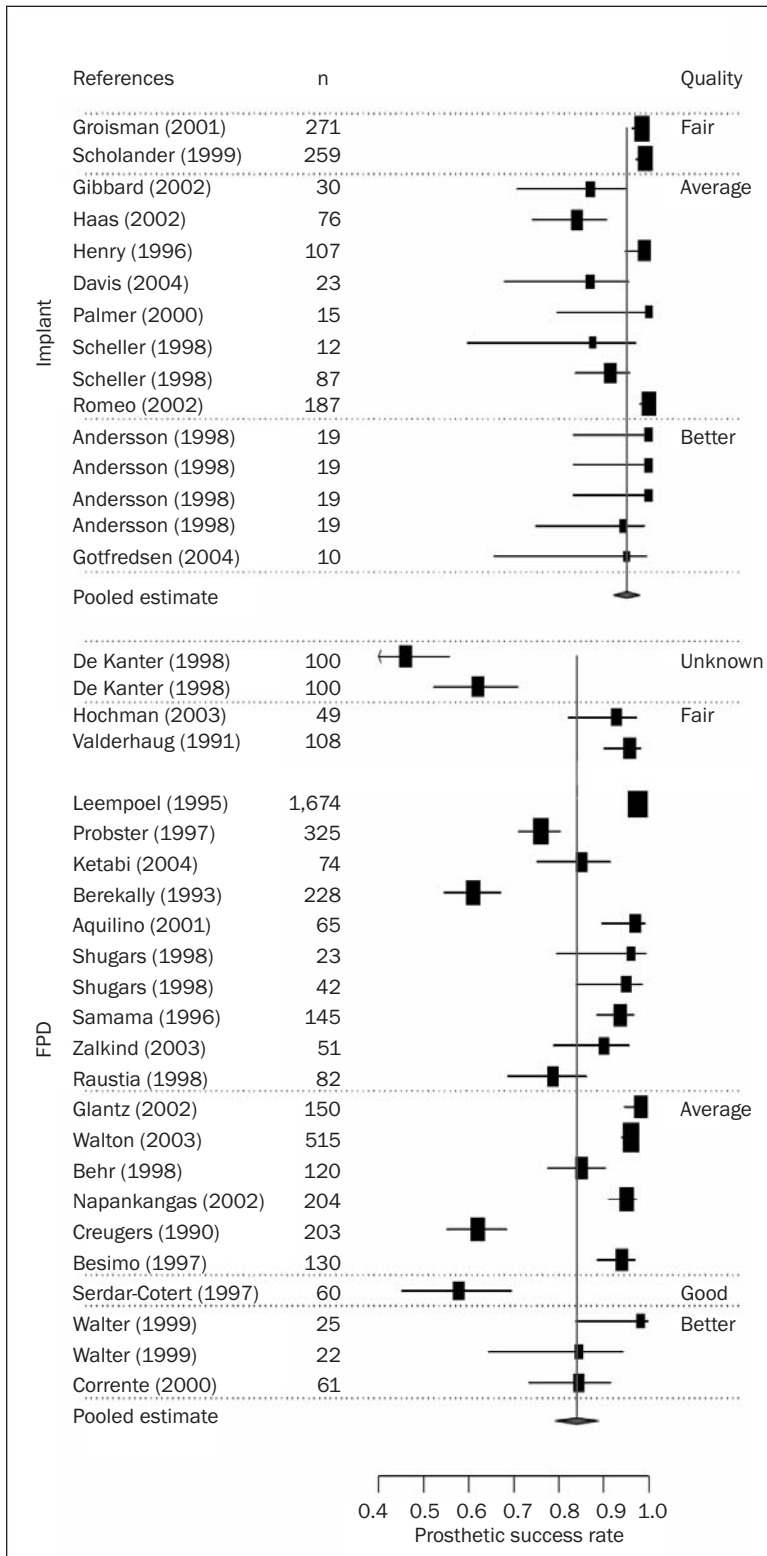
**Fig 5** Size and quality of FPD studies.



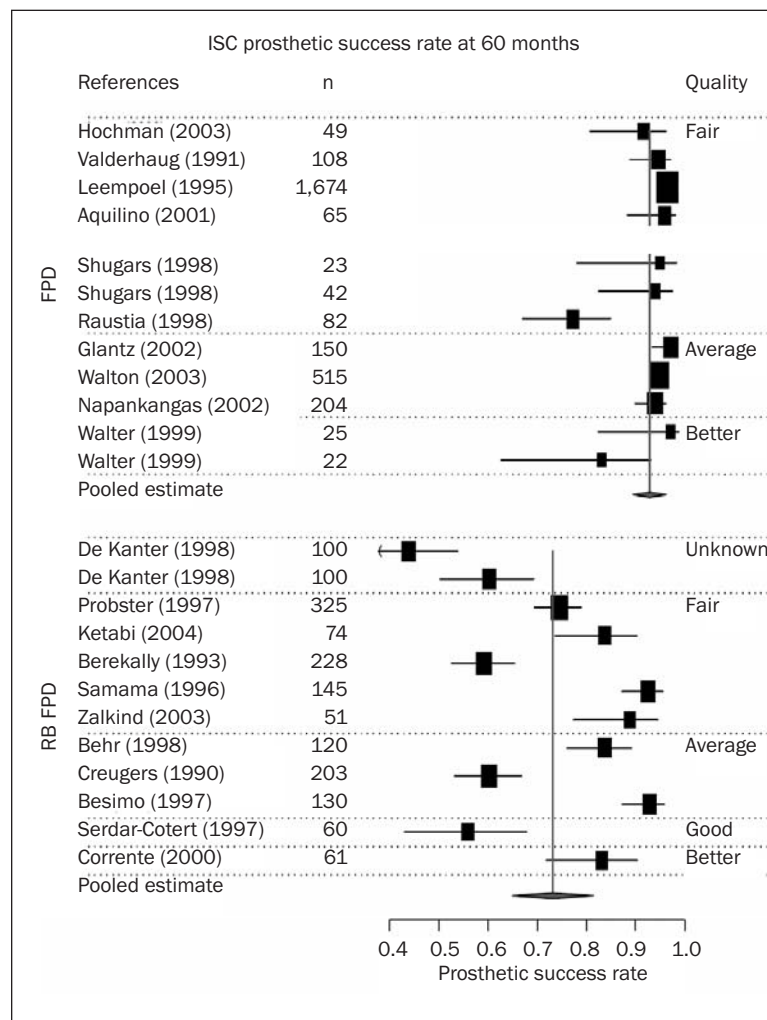
**Fig 6** ISC survival rate at 60 months.



**Fig 7** ISC prosthetic success rate at 60 months.



**Fig 8** Implant/tooth prosthetic success rate at 60 months for conventional FPDs and RBF-PDs. Note: implant success rate same as Fig 7.



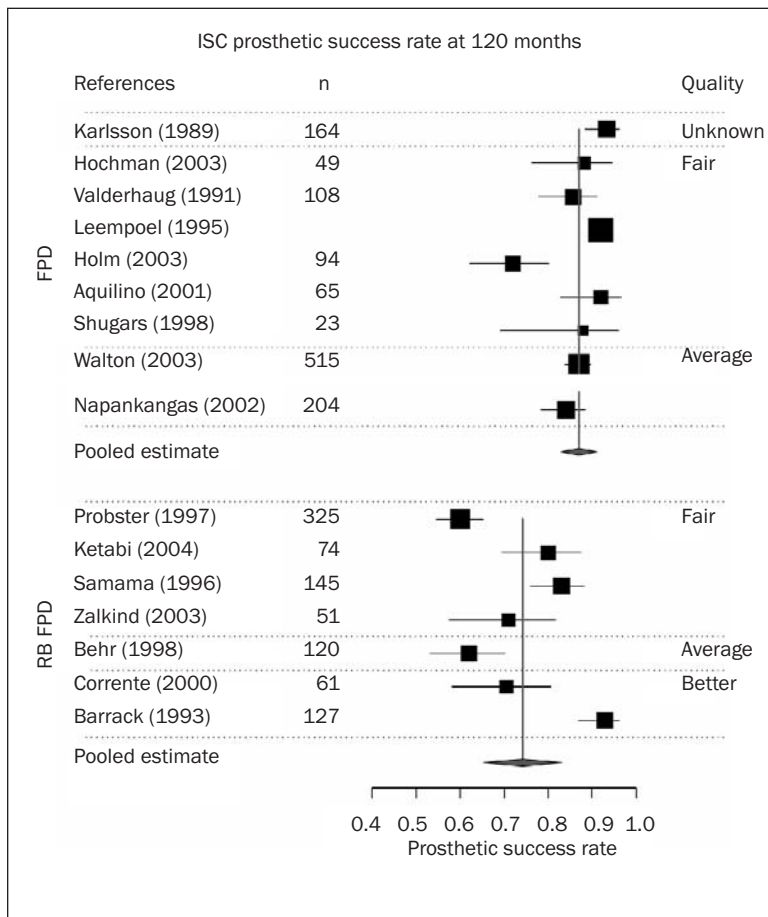
Seven ISC studies were classified as high-quality prospective studies. The studies so classified were those that were identified as RCTs,<sup>88</sup> made an effort to describe esthetic differences by 1- or 2-stage surgical approaches,<sup>186</sup> compared immediate loading of implants to delayed loading,<sup>134</sup> used a parallel arm design using different types of materials for abutment connection,<sup>20,173</sup> or prospectively analyzed parallel groups of trained clinicians.<sup>18</sup> Several of these studies had either a large group of subjects and/or long follow-up periods with minimal attrition.

Most of the studies appeared to have a low level of prosthetic complication, with the exception of 5 studies.<sup>22,23,25,74,80</sup> The increased prosthetic complication rate was perhaps related to early component designs that were originally developed for the management of edentulous patients. A total of 2,963 single-tooth restorations were examined in the 54 studies identified.

### Characteristics of FPDs

The prosthetic success rate of FPDs is shown in Fig 7 for comparison with the ISC group. A nongrouped comparison results in some difference, which is probably attributed to the variability of the RBFDPs (Fig 8). Many studies cited disease markers such as caries, periodontal disease, endodontic pathology, or structural failures but did not relate these to specific time-points demonstrating prosthetic survival relative to time. Several of the conventional FPD studies described partial veneer retainers<sup>382</sup> or cantilever designs<sup>23,289,312,355,407</sup>; the FPDs in these studies equated to less than 30% of the total number of FPDs.

Failures were attributable to mostly biologic parameters, such as caries,<sup>274,278,318,377,307</sup> periodontal disease,<sup>231,250</sup> or endodontic pathology.<sup>231</sup> Structural complications were related to retention<sup>289,416</sup> or abutment fracture.<sup>434</sup>



**Fig 9** ISC prosthetic success rate at 120 months.

Caries seemed to be the most prevalent complication in most studies, but some authors<sup>289</sup> remarked that loss of retention is usually the primary initiating factor, whereas caries becomes a secondary consequence. Others maintained that retention and caries are seen prevalently at 2 different timepoints and are unrelated.<sup>416</sup>

Data extraction from studies on RBFDPs demonstrated a greater degree of variability of long-term success. Many of the parameters for improving outcomes cited differences in preparation design, alloy selection, surface treatment of alloy, framework design, and pontic number. In contrast to the biologic failures encountered with conventional FPDs, RBFDPs demonstrated failure secondary to structural complications. Some authors maintained that preparation of the abutment teeth made a significant difference in long-term survival.<sup>197,200,203,375</sup> Other studies did not corroborate this suggestion.<sup>368</sup> Alloy treatment with etching alone versus silicoating was found to enhance retention in some studies and make a significant difference in long-term survival.<sup>299,368</sup> Other studies showed that this factor is not a consideration

in long-term survival.<sup>375</sup> Base metal alloys seem to enjoy a resistance to debonding in comparison to palladium alloys. Most of the studies indicated that debonding at the resin-metal interface is the weak link and that stresses leading to debonding are transferred to this interface. Despite suggestions for all of these preparation variables, contemporary materials, and surface treatments, the long-term predictability remains highly variable. Survival data at the 60-month timepoint were demonstrated in studies by Berekally and associates,<sup>203</sup> Probster and Henrich,<sup>368</sup> and Creugers and colleagues.<sup>237</sup>

Six studies were rated as better studies because of their prospective design.<sup>235,237,238,377,390,429</sup>

Single implant-supported restorations demonstrated apparent high surgical success rates and high prosthetic success rates. Surgical failures appear to occur early. Prosthetic complications also appear to occur early and gradually taper off over time. Prosthetic success at 60 months was 95.1% (CI: 92.2%–98.0%). The 60-month timepoint was chosen to survey the greatest number of studies that documented follow up at this specific time.

FPD success was analyzed in 2 different ways. The first method combined conventional FPDs with RBFPDs. For this population, prosthetic success was examined at 60 months (84.0%; CI: 79.1%–88.9%; Fig 7), 120 months (81.3%; CI: 75.9%–86.7%; Fig 9), and 180 months (67.3%; CI: 50.1%–84.5%). The second method of analysis was to look only at FPDs retained conventionally. Prosthetic success was 94.0% (CI: 90.7%–97.3%) at 60 months (Fig 8), 87.0% (CI: 82.8%–91.2%) at 120 months, and 67.3% (CI: 50.1%–84.5%) at 180 months.

Several trends are noted within the population of each group (Table 1). For example, implant-supported prostheses were at higher risk soon after implant placement. The ongoing risk of implant failure was relatively low, but confidence intervals widened as long-term study enrollment diminished. Also, FPD studies did not evaluate clinical performance at early stages. FPD studies were longer-term studies, and confidence intervals were quite wide because of patients/prostheses that were lost to follow-up or low long-term study populations. Also, more studies of implant-supported prostheses than FPD studies were found in the “better” and “best” groups. Finally, FPD studies tended to be smaller studies of lower quality.

## DISCUSSION

The State of the Science of Implant Dentistry was originally conceived as a systematic review of the scientific literature as it relates to implant and natural tooth-supported restorations. This systematic review addressed the PICO question, “In patients requiring single-tooth replacement, what are the outcomes of implant- as compared to tooth-supported restorations?” No direct comparative studies were identified through this review. However, during the data gathering phase of this review, it was clear that a large volume of scientific literature is available on the subject of survival of ISCs and FPDs. This information served to provide the bulk of this review. Efforts were made to be as inclusive as possible when selecting articles. This resulted in a large number of articles for both comparison groups.

During the course of data extraction and analysis it became quite clear that direct comparisons of these 2 treatment groups would be difficult. The primary reasons for this were related to the large number of different treatment interventions and the myriad of reporting methods used by authors. In addition, the treatment periods were quite different between tooth- and implant-supported restorations. After comprehensive data extraction was performed,

**Table 1 Pooled Data at 60, 120, and 180 Months**

Population/timepoint	Pooled success (%)	CI (%)
Implant-supported restorations		
60 mo	95.1	92.2–98.0
120 mo	—	—
180 mo	—	—
Tooth-supported FPDs		
60 mo	94.0	90.7–97.3
120 mo	87.0	82.8–91.2
180 mo	67.3	50.1–84.5
RBFPDs		
60 mo	74.7	66.6–82.8
120 mo	74.2	65.3–83.1
180 mo	—	—

it was clear that the primary outcome for assessment was simply survival of the restoration, retaining teeth, or implants. The exact mode of failure was rarely determined through assessment of the available literature. Furthermore, direct comparison between specific time periods was generally not possible. In general, implant studies reported earlier data, while tooth-supported studies demonstrated more long-term data. The exception to this occurred with the etched and bonded tooth-supported restorations; these reports were generally shorter in duration than the other fixed prosthodontic reports.

In preparing this systematic review, the reviewers were faced with a number of dilemmas. The variety of procedures performed in fixed prosthodontics on natural teeth is quite broad. Although it was tempting to separate data from etched and bonded restorations from the data pertaining to more conventional fixed prosthodontic therapy, doing so would have negated treatment that had been originally described as definitive care. In retrospect, that definitive care may not have been as long-lasting as anticipated when the procedures were planned. Of course, there is recognition that any study could lead the investigators in positive or negative directions; it is this uncertainty that is the reason for the investigation. Accepting this, the reviewers have provided data regarding all fixed prostheses of all designs and have also separated the data from the etched and bonded restorations from more conventionally retained restorations.

In the implant literature there are a number of different implant designs, manufacturers, prosthetic designs, and general treatment approaches that have been used. Once again, it was difficult to establish a subcategory for each treatment method. Consequently, the data from implant-supported prostheses were analyzed primarily as related to implant survival and subsequent prosthetic survival.

In both literature sets there was a distinct lack of consistent data reporting based upon specific time periods. Many articles described the survival only at the end of a study period, while other articles provided life table data from annual patient reassessments. When considering studies that have not provided time-dependent data, it is often difficult to determine the actual length of service for any specific prosthesis. For example, an article that describes 10-year results of a certain treatment method may actually be reporting results of prostheses in place for a period ranging from days to 10 years. Many of these studies failed to report the mean time of service; it was left up to the reader/reviewer to interpret this time of service.

Direct comparison of the implant- and tooth-supported prosthetic results, given the lack of comparative time periods, was virtually impossible. Despite the large volume of literature that exists on both topics, the direct comparison of treatment outcomes for specific time periods was not realistic. To address the situation it was necessary to either provide descriptive results or attempt to consider the slope of survival graphs, looking at survival relative to time. But even this was not possible, given the fact that many of the studies lacked annualized data. The situation was further complicated by studies that provided only cross-sectional data, as inclusion of these studies into a larger database could not be done with confidence.

Understanding all the aforementioned caveats, the reviewers have attempted to provide their impressions of the survival relative to time. Two distinct impressions are drawn from this information. Survival within implant-supported prostheses demonstrates a rapid, although small, early decline followed by long-term stability. Once the early failure period (generally the result of failure of the implant to achieve integration with bone) has passed, the prostheses appear to demonstrate a predictable long-term service. The overall early failure rate is generally less than 5% during the first year of service. Over the next 5 to 10 years, the failure rate diminishes.

In contrast, fixed prostheses supported by natural teeth appear to have very low early failure rates. The exception to this occurs with etched and bonded restorations, where some reports demonstrate surprisingly high early failure rates in comparison to conventionally retained FPDs. Long-term survival of fixed prostheses supported by natural teeth appears to be lower than the projected long-term survival of prostheses supported by dental implants. However, this statement is the result of extrapolation rather than an observance of long-term survival curves, since those studies do not exist for ISCs.

Most of the published scientific literature concentrated on simple survival of dental implants and simple survival of FPDs. However, other criteria for implant success exist which are not routinely applied. The reason for this could be reluctance on the part of the authors to claim "success," inability on the part of the authors to assess success, or realization that the success criteria are too stringent for the implants used in the authors' studies. Regardless of the reason, most implant studies continue to discuss survival alone but have cloaked this discussion under the terms of success. In addition, few studies have described complications associated with implant therapy. Clinicians certainly recognize that a number of complications can occur with implant-supported prostheses. Implant failure or fracture, screw loosening or fracture, material wear or fracture, and failure of luting agents are the most commonly described complications. It is also recognized that implant malposition, soft tissue recession, bone loss, and unfavorable soft tissue configuration, texture, or color are complications that must be reported. Since these factors have not been consistently reported, it is the recommendation of the authors of this systematic review that it become standard procedure to record and report these elements in future scientific publications.

Returning to the initial premise of the State of the Science of Implant Dentistry workshop, it seems appropriate to state that definitive answers cannot be drawn from this systematic review of the literature. Generalized impressions of the data provide the reviewers with a perception of the outcome from the 2 different treatment arms, but this impression is the result of data interpretation rather than simple data analysis.

Accepting the notion that the scientific data are not available to answer the question posed by this workshop, it may be prudent to consider future avenues of investigation that could achieve this purpose. Certainly it would be almost impossible to create a single scientific study that would definitively address the question of the superiority of either implants or natural teeth as a means to support prostheses. Instead, it may be more prudent to realize that a series of investigations could be used to address this question. In that event, clinicians would benefit from consistent reporting of observed outcomes. The routine use of life tables with outcomes reported on an annual basis would make the task of data compilation much easier. In this situation, an individual could compile data from published research, thereby creating a low living low-level systematic review. Likewise, comparison of studies that use this method of data reporting would be a simpler process. The average clinician could create

spreadsheets that included pertinent references and data extracted from those references to be used in clinical practice. This recommendation alone would, if followed, provide the basis for a future systematic review that could provide definitive answers to the questions posed.

It is also important to understand that the information that was available in the scientific literature primarily related to survival of implants, teeth, or prostheses. There are a number of other complications that can occur but are not routinely reported. Material fracture or wear; biologic complications such as dental caries, gingivitis, or periodontitis; tooth or implant fracture; loss of retention; and cosmetic dissatisfaction should all be reported. Should future reports include this information, the literature will convey a much better understanding of the factors that influence treatment outcomes. Likewise, this information could be shared with patients to establish a truly informed consent.

Other suggestions to authors and editors are that future studies should include a minimum of follow-up time of 1 year for the majority of implants in the study. When comparative studies are performed, a sufficient number of subjects must be enrolled in each study arm to allow meaningful comparisons. Failure to populate studies with adequate numbers of subjects in each study arm results in insignificant differences even when clinical observations differ. Although statistical methods such as the Kaplan-Meier survival curves provide the probability of survival at specific timepoints, these methods of analysis do not lend themselves well to data extraction when systematic reviews are conducted. For this reason, it may be prudent for authors to include life tables along with Kaplan-Meier curves in future publications. Including both approaches to data analysis will facilitate future data extraction. In addition, when studies are underpopulated, data from the underpopulated study will be readily extracted for inclusion in larger synthesized studies.

Since the results of this systematic review demonstrated that most implant designs perform within 5% of each other, comparative studies of different implants designed to compare survival differences are unlikely to succeed in this regard, unless there are hundreds of implants in each study arm. If implant and prosthetic success are the compared outcomes, the study populations may not need to be as large.

It is the goal of this report to make suggestions which will allow future analyses to encompass more meaningful data at multiple timepoints. Inclusion of the parameters of absolute failure (ie, the causes for retreatment) is essential for meaningful data analyses. Likewise, general categories of complications

would be valuable for the clinician. Descriptions of need for retreatment—prosthetic material failure (restorative material failure, connector failure, component failure), implant failure (loss of integration or fracture), esthetic failure (eg, shade, contour, position), implant angulation, soft tissue or inadequacy, or bone loss—need to be categorized appropriately. Likewise, there can be complications in each of these areas that do not require retreatment but do require additional treatment to maintain, repair, or correct a problem/complication.

It is hoped that future analyses can incorporate more in-depth data to arrive at multiple timepoint conclusions and predict the behavior of implant- and tooth-supported restorations.

## CONCLUSION

This systematic review of the scientific literature failed to demonstrate any direct comparative studies assessing clinical performance of single ISC and FPDs. The study suggests differences at 60 months between survival of ISCs and FPDs when resin-bonded and conventionally retained fixed prostheses were grouped. This difference disappeared when ISCs were compared with conventionally retained FPDs at 60 months. For other time periods, direct comparative data were unavailable.

## ACKNOWLEDGMENTS

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## SECTION 3 CONSENSUS REPORT

### In patients requiring single-tooth replacement, what are the outcomes of implants as compared to tooth-supported restorations?

Members of Section 3 evaluated the systematic review on the outcomes of replacing single teeth with implants as compared with conventional segmental prostheses. The focused PICO question addressed by the authors, Thomas J. Salinas and Steven E. Eckert, of the evidence-based systematic review is: In patients requiring single-tooth replacement, what are the outcomes of implant- as compared to tooth-supported restorations?

An overriding issue that arose in the formation of this systematic review was that there are no comparative studies of fixed partial dentures (FPDs) and implant-supported crowns (ISCs). Thus, criteria were selected to allow enough time following prosthetic loading (>2 years post-implant placement) with a sufficient number of samples being followed (>12) that would allow for attrition. The consensus of the section was that the inclusion/exclusion criteria were appropriate. These were: (1) >2-year follow-up; (2) >12 restorations; (3) English language; (4) a “pure” single-tooth replacement study in humans (ie, a study that clearly identified single-tooth restorations relative to other restorations and involved a bounded edentulous space; and (5) data presented with success or survival.

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

The section agreed that the review was complete under the parameters of the inclusion and exclusion criteria. It is important to recognize a limitation of this review was that the outcomes were assessing a time-oriented process to retreatment. Ultimately this is a prosthetic question. Therefore, need for retreatment equals failure. The primary outcome evaluated was implant retention or fixed partial denture survival. In most instances the study did not define success criteria even though “success” was reported. The lack of consistency forces this process to accept the criteria used by the respective author (and the editorial process).

There were attempts made to address the secondary outcomes such as bone loss, caries, etc. But the section found only a few studies systematically reported on these key features, so it was necessary to revert to the simple criteria of success or survival.

#### 2. Has any new information been generated or discovered since the review cut-off date?

An online search was performed during the session in addition to the preconference updated search. Five articles were identified and printed; each was assigned to paired section members who provided an assessment for inclusion. If found to meet the inclusion criteria, data extraction would be performed. Focus was on the potential impact and possible modification to the conclusions of the review article. The section found there were new published studies since May 2005 but none of the cited studies were of significant size or outcomes that would influence the conclusions of the review. These studies were:

- Romeo E, Lops D, Amorfini L, Chiapasco M, Ghisolfi M, Vogel G. Clinical and radiographic evaluation of small-diameter (3.3-mm) implants followed for 1–7 years: A longitudinal study. *Clin Oral Implants Res* 2006;17:139–148. The section could not distinguish between single-tooth versus implant FPDs in this study. There was also a dilemma that survival was cited as being less than success. Therefore, the section decided to exclude this study.
- Elkhoury JS, McGlumphy EA, Tatakis DN, Beck FM. Clinical parameters associated with success and failure of single-tooth titanium plasma-sprayed cylindrical implants under stricter criteria: A 5-year retrospective study. *Int J Oral Maxillofac Implants* 2005;20:687–694. The section found that this study was not based on original research but was a retrospective survey of a larger prospective study. Therefore, the section decided to exclude this study.
- Lindeboom JA, Frenken JW, Dubois L, Frank M, Abbink I, Kroon FH. Immediate loading versus immediate provisionalization of maxillary single-tooth replacement: A prospective randomized study with BioComp implants. *J Oral Maxillofac Surg* 2006;64:936–942. The section found that this study was only from 6 months to 1 year follow-up. Therefore, the section decided to exclude this study.

- Wennstrom JL, Ekestubbe A, Grondahl K, Karlsson S, Lindhe J. Implant-supported single-tooth restorations: A 5-year prospective study. *J Clin Periodontol* 2005;32:567–574. The section found that this study was eligible for inclusion (40 subjects, 45 implants, 40 in maxillae and 5 in mandibles, up to 5-year outcomes).
- De Backer H, Van Maele G, De Moor N, van den Berghe L, De Boever J. A 20-year retrospective study of fixed partial dentures. *Int J Prosthodont* 2006;19:143–153. The section found this to be a 20-year follow-up from a predoctoral dental student clinic (193 patients, 322 FPDs). There was no life table data presentation, making data retrieval impossible. Also, the sample size was small relative to the overall pooled sample of 6,000 FPDs; therefore, inclusion of this study would have little impact on the conclusions of the review.

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

The section found there was a conclusion that was not supported by the data. The conclusion was a subjective statement that implants fail early and fixed prostheses fail later. Implant-supported crown studies simply do not follow clinical performance for time periods that were similar to the studies following FPDs. The ISC studies were typically up to 6 years in duration, while FPD studies extended to more than 10 years. ISC research was a mixture of prospective and retrospective studies, while FPD data were retrospective in nature. The conclusion was therefore withdrawn.

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

The section concluded that additional research is needed to identify diagnostic and outcome variables (clinical and patient-specific): clear clinical success and survival *clinical criteria* coupled with relevant *patient-specific risk factors* (eg, psychological; eco-

nom; masticatory; genetic/anatomic/biologic; structural; QOL, etc) must be developed. A method to obtain these variables may be the goal of a future consensus conference. Different studies had different levels of outcome variance.

The section agreed that research is needed to identify variables (confounders) that can be explanatory for the variance observed in clinical trials.

The section felt there must be a standard template for data collection, presentation, and publication. This would not prevent the ability of clinical case-series to be a part of the literature. A consensus conference may be needed to obtain this template. The section report calls for increased diligence on the part of authors to submit data outcomes, relative to specific timepoints, that will allow future extraction and pooling of data in systematic reviews. This will assist clinicians to continue to manage implant patients over the long-term for those patients being consistently reevaluated. Journal editors are encouraged to continue to accept manuscripts describing ongoing systematic recall of patients. Finally, the section felt *comparative studies* of dental outcomes relative to implant restorations are needed. Examples would be investigator-initiated multicenter trials, NIH, industry-based consortiums, etc.

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

The section felt application to patient management will be used to identify the strengths and weaknesses of each therapy. Patients should be advised of the significant difference in outcomes between resin-bonded FPDs and conventional FPDs or single-tooth implant restorations. The section felt it was important that based on the implant systems included in this review, patients may be advised that there is little variability in implant survival. The section concluded that this assessment will assist in the development of patient-specific factors and thus assist in the formulation of a treatment decision tree.

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