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A Critical Review of Diabetes, Glycemic Control and Dental Implant Therapy

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Abstract

Objectives—To systematically examine the evidence guiding the use of implant therapy relative to glycemic control for patients with diabetes and to consider the potential for both implant therapy to support diabetes management and hyperglycemia to compromise implant integration.

Material and Methods—A systematic approach was used to identify and review clinical investigations directly assessing implant survival or failure for patients with diabetes. A MEDLINE (PubMED) database search identified potential articles for inclusion using the search strategy: (dental implants OR oral implants) AND (diabetes OR diabetic). Inclusion in this review required longitudinal assessments including at least 10 patients, with included articles assessed relative to documentation of glycemic status for patients.

Results—The initial search identified 129 publications, reduced to 16 for inclusion. Reported implant failures rates for diabetic patients ranged from 0–14.3%. The identification and reporting of glycemic control was insufficient or lacking in 13 of the 16 studies with 11 of these enrolling only patients deemed as having acceptable glycemic control, limiting interpretation of findings relative to glycemic control. Three of the 16 studies having interpretable information on glycemic control failed to demonstrate a significant relationship between glycemic control and implant failure, with failure rates ranging from 0–2.9%.

Conclusions—Clinical evidence is lacking for the association of glycemic control with implant failure while support is emerging for implant therapy in diabetes patients with appropriate accommodations for delays in implant integration based on glycemic control. The role for implants to improve oral function in diabetes management and the effects of hyperglycemia on implant integration remains to be determined.

Keywords

Diabetes; dental care; implant; glycemic control; literature review

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Introduction

Diabetes mellitus is a chronic metabolic disorder that affects 25.6 million individuals or more than 11% of the adult US population. This prevalence represents a 28% increase in the number of patients with diabetes since 2005 (CDC 2005, 2008). Current projections of diabetes incidence suggest that as much as 33% of the US population may be diagnosed with diabetes by 2050, with type 2 diabetes mellitus accounting for 90 to 95% of all diabetes patients (Boyle, et al. 2010). World-wide over 150 million people were estimated as having diabetes in the year 1980, and that number had grown to over 350 million by 2008 (Danaei, et al. 2011). Taken together, these trends highlight the urgency for better understanding diabetes as well as for improving the care of patients with diabetes.

Diabetes mellitus has long been considered a relative contraindication to dental implant therapy and is increasingly becoming one of the most commonly encountered contraindications to dental implant therapy (Oikarinen, et al. 1995). Unfortunately, our understanding of diabetes mellitus as a relative contraindication based on the patient's level of glycemic control has changed little since the 1988 NIH Consensus Conference on Dental Implants (National Institutes of Health Consensus Development Conference 1988, World Workshop in Periodontics 1996, Blanchaert 1998, Wilson & Higginbottom 1998, Beikler & Flemmig 2003, Kotsovilis, et al. 2006, Javed & Romanos 2009). As a result, well-controlled diabetic patients may be considered appropriate for implant therapy while diabetic patients lacking good glycemic control may be denied the benefits of implant therapy.

The overall goal of this review is to critically assess the evidence available for the use of implant therapy for patients with diabetes based on glycemic control. Importantly, clinical studies directly examining the relationship between diabetes and implant survival, and the potential for glycemic control to serve as an appropriate discriminator for the application of care, are evaluated using a systematic approach. Additionally, the use of implant therapy in special populations requires consideration of potential benefits to be gained from the therapy. In order to better appreciate this potential, the literature is reviewed relative to the benefit gained from implant therapy in a functionally debilitated situation, that is, for edentulous patients. Similarly, the literature is reviewed relative to the effects of hyperglycemia on implant integration as diabetes-related alterations in bone metabolism may have direct effects on osseointegration and implant survival in this patient population.

Material and Methods

A systematic approach was used to identify and review evidence guiding our use of implant therapy relative to glycemic control for patients with diabetes. Additionally, an overview of potential benefits of implant therapy and the risks associated with hyperglycemia on bone metabolism as critical to implant success were performed using a traditional narrative of relevant literature.

Study selection

To be eligible for inclusion in this review, clinical investigations needed to directly assess implant survival or failure for patients with diabetes. Where possible, failure rates were determined based on the total percentage of implants placed (implant failure rate) and based on the total percentage of patients experiencing at least 1 implant failure (patient failure rate). Studies had to be longitudinal in nature. Prospective and retrospective studies with at least 10 patients treated were considered for inclusion. Articles in French, German and English were considered for possible inclusion.

Search strategy

A search in the MEDLINE (PubMED) database up to and including July 2011 for articles published in the dental literature was performed. The search strategy applied was: (dental implants OR oral implants) AND (diabetes OR diabetic). A limit to “human” studies was applied to the search query.

In addition, the reference lists of publications selected for inclusion in this review were systematically screened.

Validity assessment

The screening of the search results for possible inclusion was conducted independently by two reviewers (T.W.O & G. H-B.). The discrepancies were resolved by discussion.

Results

The search resulted in the identification of 129 publications. Independent initial screening of the titles and summaries with respect to the question reviewed resulted in further consideration of 51 publications. If the abstract was not available, the full text was obtained for further screening. Based on available abstracts, 22 publications were further excluded.

Thus, out of the initial 129 titles, 100 were excluded based on screening of the titles and abstracts. The reasons for exclusion included:

- Review article
- Cases series with less than 10 patients treated
- In vitro studies
- No patient with diabetes included
- No data on dental implant survival/failure rate

A total of 29 full texts were obtained and ultimately 16 full text articles were included in the present review. At the full text article level, 13 articles were excluded for the following reasons:

- Review article (Garg 2010)
- Cases series with less than 10 patients treated (Smith, et al. 1992, Alsaadi, et al. 2008b, Maximo, et al. 2008, Lee, et al. 2010)
- No data on implant survival rate in diabetic patients (Ferreira, et al. 2006, Alsaadi, et al. 2007, Doyle, et al. 2007, Huynh-Ba, et al. 2008, Aloufi, et al. 2009, Lee, et al. 2010)
- Same patient population as other study already included (Hamada, et al. 2001, Roumanas, et al. 2002, Oates, et al. 2009)

The manual search of the references of the included publications identified one article (Kapur, et al. 1998), which was included to the present review. However, this was the first article of subsequent publications based on the same patient population (Garrett, et al. 1998, Hamada, et al. 2001, Roumanas, et al. 2002) Therefore the publication by Garrett and coworkers (1998) which was previously included based on the electronic search was excluded and replaced by the publication by Kapur and coworkers (1998). Ultimately, a total of 16 publications were included for review following the selection process. The Kappa values for inter-reviewer agreement for inclusion of publications at the title, abstract and full text level were 0.79, 0.80, 0.86 with a 95% confidence interval (CI) of 0.69–0.90, 0.64–0.97,

0.68–1.05, respectively. These Kappa scores indicated “good” to “very good” inter-reviewer agreement (Fig. 1). The details and characteristics of these included studies are presented in Tables 1 and 2.

Secondarily, the 16 reports identified were categorized based on their completeness in the consideration and reporting of methodology for assessments of glycemic control, as well as qualitative and quantitative stratifications of glycemic control. Those reports containing all 3 components were considered separately in the review (Table 2).

Discussion

Glycemic Control

Glycemic control is a primary consideration for patients with diabetes. There is a clear correlation between glycemic control and the development of microvascular and macrovascular complications (Cohen & Horton 2007). Glycated hemoglobin A1c, HbA1c, is a frequently used diagnostic and therapeutic measure of blood glucose control. This value represents the percent of glycated A1c hemoglobin in red blood cells. Because this value is based upon the average circulating time of a red blood cell, 60–90 days, it reflects longer-term or average blood glucose levels over two to three months. Elevated HbA1c levels correlate directly with morbidity and mortality in diabetes (Boltri, et al. 2005). Therefore, achieving low HbA1c levels serves as an important therapeutic target in the management of diabetes (Wysham 2010). Recent recommendations for strict glycemic control for persons with diabetes have targeted maximal HbA1c levels ranging from 6.5% up to 7.0% (Rodbard, et al. 2009, Standards of medical care in diabetes. 2010).

In that glycemic control depends in large part on proper dietary management, it is the individuals with significant oral debilitation and elevated glycemic levels who may have the most to gain from improvements in oral function associated with implant therapy. In view of the increased prevalence of type 2 DM in ethnic minorities (including 14.7% in African Americans, 11% in Hispanics, and 18% in American Indians), coupled with barriers to care, these populations are at even greater risk for hyperglycemic complications (Peek, et al. 2007). Especially in the case of minority groups, for whom HbA1c levels are more commonly elevated, the adverse effects of compromised oral function may serve as an additional obstacle to optimal glycemic control (Boltri, et al. 2005, Choi, et al. 2011).

Masticatory Function and Diabetes

Periodontal disease frequently results in tooth loss, with the cumulative effects most significant in older patients (Albandar, et al. 1999). It is these older patients who are also particularly susceptible to type 2 diabetes and its comorbidities. Diabetes has been shown to significantly increase the levels of periodontal disease and tooth loss (Emrich, et al. 1991, Safkan-Seppala & Ainamo 1992, Oliver & Tervonen 1993, Collin, et al. 1998, Oliver, et al. 1998). Thus, one of the more subtle complications of diabetes may be a decrease in a patient’s health and quality of life due to tooth loss and compromised function (McGrath & Bedi 2001).

Edentulism represents a dramatic debilitation in oral health and function. Importantly, compromises in masticatory function that lead to alterations in dietary behaviors for diabetic patients may be an essential consideration in the overall disease management for these patients, directly impacting glycemic control (Kawamura, et al. 2001, Nuttall, et al. 2003, Roumanas, et al. 2003, Savoca, et al. 2010). Numerous studies have provided strong evidence of an association between diminished chewing function and the amount of fruits, vegetables, meats and breads that edentate individuals consume. These reductions of healthy food consumption lead to dietary deficiencies in vitamins, minerals, fiber and proteins.

Edentate individuals then compensate calorically with a diet higher in fats and cholesterol (Osterberg & Steen 1982, Appollonio, et al. 1997, Ritchie, et al. 1997, Papas, et al. 1998, Mojon, et al. 1999, Sheiham, et al. 2001, Hutton, et al. 2002, Savoca, et al. 2010). In fact, the edentate condition and compromised masticatory function have been associated with malnutrition (Shigli & Hebbal 2010, Tsakos, et al. 2010). Difficulties in chewing and swallowing have also been identified as indicators of nutritional risk in older adults and ethnic minorities (Bailey, et al. 2004, Wu, et al. 2011). Therefore, oral health and, specifically, functional tooth replacement must be considered in the overall dietary and nutritional management of patients with diabetes (Quandt, et al. 2009).

Recent work has shown that complete denture wearers benefit greatly when even as few as 2 implants are used to retain their mandibular dentures, reporting significantly higher satisfaction and better oral health-related quality of life (Boerrigter, et al. 1995, Awad & Feine 1998, Awad, et al. 2003, Heydecke, et al. 2003, Thomason, et al. 2003, Meijer, et al. 2004). In a randomized trial, 60 independently living edentate males and females (aged 65–75 yrs) received either new conventional dentures or maxillary conventional dentures and mandibular 2-implant overdentures. Six months after wearing their new prostheses, those in the implant group reported being less limited in their choice of food and having less need to drink in order to swallow. They also reported significantly less difficulty chewing pieces of meat, as well as whole, hard vegetables (including carrots) and fruits (raw apples) than those who received the conventional dentures (Morais, et al. 2003). These results were recently replicated in a similar study with 283 edentate elders (Feine - unpublished results). The ability of edentate people to freely choose the foods they wish will allow them to eat fresher, healthier fare.

Our literature search revealed only one study investigating the impact of implant therapy on treatment satisfaction in a diabetic population (Kapur, et al. 1999). In a randomized trial, new maxillary and mandibular dentures were delivered to edentate diabetic patients. Of 89 subjects, 37 received maxillary and mandibular conventional dentures and 52 received a maxillary conventional denture and a mandibular 2-implant overdenture. While both groups showed improvements with their new prostheses, those patients with implant-retained overdentures had greater improvement in eating enjoyment, speech and general satisfaction. Also, a higher percentage of patients in the implant-retained overdenture group reported pre- to post-treatment improvements in chewing ability, chewing comfort, and denture security. However, this study failed to detect a difference in food choices, supporting the importance of dietary counseling as part of denture therapy (Oikarinen, et al. 1995, Roumanas, et al. 2003).

It is the aging population in which both tooth loss and type 2 diabetes mellitus coexist that the need may be greatest and for whom implant therapy may offer the greatest benefit. There is clearly the potential for implant-based oral rehabilitation to enhance the well-being of patients with diabetes. However, many of the benefits of implant therapy in patients with diabetes remain to be determined.

Bone Metabolism and Diabetes Mellitus

Dental implant survival is initially dependent upon successful osseointegration following placement. Subsequently, as an implant is restored and placed into function, bone remodeling becomes a critical aspect of implant survival in responding to the functional demands placed on the implant restoration and supporting bone. The critical dependence on bone metabolism for implant survival may be heightened in patients with diabetes.

Type 1 diabetes has been consistently associated with osteopathic outcomes. Numerous clinical assessments have shown decreased bone mass, alterations in bone turnover, and

increased risk of bone fractures (Krakauer, et al. 1995, Hampson, et al. 1998, Christensen & Svendsen 1999, Campos Pastor, et al. 2000, Kemink, et al. 2000, Espallargues, et al. 2001, Valerio, et al. 2002, Heilman, et al. 2009). These findings are also consistent with numerous animal studies showing negative effects of hyperglycemia, not only on bone formation, but also on bone strength and fracture healing (Devlin, et al. 1996, Forsen, et al. 1999, Inaba, et al. 1999, Funk, et al. 2000, Gooch, et al. 2000, Alkan, et al. 2002, Amir, et al. 2002, Beam, et al. 2002, Gebauer, et al. 2002, Follak, et al. 2003, Lu, et al. 2003, Follak, et al. 2004, Liu, et al. 2006, Kayal, et al. 2007). Similarly, decreased levels of implant osseointegration have been consistently demonstrated in hyperglycemic animals consistent with untreated type 1 diabetes (Siqueira, et al. 2003, de Morais, et al. 2009)

In contrast to type 1 diabetes, the effects of type 2 diabetes on bone turnover remain uncertain. Several studies have identified bone mineral densities consistent with or greater than non-diabetic patients, and lower or no difference in fracture rates (Barrett-Connor & Holbrook 1992, Bauer, et al. 1993, van Daele, et al. 1995, Forsen, et al. 1999, Tuominen, et al. 1999, Nicodemus & Folsom 2001, Sosa, et al. 2009). However, in a large prospective study of osteoporotic fractures, it was found that women with type 2 diabetes had higher fracture rates than non-diabetic women, even with higher bone mineral density in the diabetes patients, suggesting qualitative differences in the bone of diabetic patients (Schwartz, et al. 2001). Additionally, two systematic reviews of risk factors for fractures identified type 2 diabetes as a moderate risk factor (RR=1.57–1.67), consistent with gender, smoking, and family history of osteoporotic fracture (Espallargues, et al. 2001, Ottenbacher, et al. 2002).

More recent meta-analyses similarly identified direct associations between type 2 diabetes and increased risk of fracture, but failed to find an association between HbA1c levels and fracture risk (Janghorbani, et al. 2006, Vestergaard 2007, Asano, et al. 2008). These findings are consistent with another study of type 2 diabetic patients that showed no association between bone density and HbA1c while duration of diabetes remained in question (Janghorbani, et al. 2006, Asano, et al. 2008). In contrast, in a population of initially poorly controlled patients (mean HbA1c>10%), biochemical markers of bone resorption were reduced in association with improved glycemic control, suggesting that hyperglycemia in patients with type 2 diabetes has adverse effects on bone metabolism (Okazaki, et al. 1997, Okazaki, et al. 1999).

Diversity within type 1 and type 2 diabetic patient populations has been proposed to account for these differences in results (Krakauer, et al. 1995, Masse, et al. 2010). These differences may include the timing of onset of the two diseases relative to the development of peak bone mass, patient characteristics typical of these two diseases (e.g., obesity, levels of glycemic control), or the regulatory interplay between insulin and bone metabolism (Basu, et al. 2011, Clemens & Karsenty 2011). In addition, measures frequently used in assessing the effects of diabetes on bone metabolism (i.e., fracture rate) may also be susceptible to confounding factors such as differences in risk of falling due to hypoglycemic episodes. Variation in the duration or severity of the diseases leading to the onset of diabetic complications, such as retinopathy, nephropathy, or neuropathy, may also affect the likelihood of falling and, subsequently, fracture rates (Ivers, et al. 2001, Patel, et al. 2008). Furthermore, it has been proposed that diabetes leads to decreased bone turnover, with reductions in both resorption and formation and that it is the difference in ages of onset of types 1 and 2 diabetes relative to bone growth patterns that lead to these distinctions in outcomes (Krakauer, et al. 1995). For example, decreased bone turnover during the period of skeletal growth in type 1 diabetes patients may attenuate formation during this period of bone growth, resulting in a decreased peak bone mass in these patients. In contrast, decreased bone turnover in older, type 2 diabetes patients may actually be protective by maintaining bone density during periods of

net bone loss in older non-diabetic individuals. While bone density may be protected, bone metabolism and healing associated with implant placement may be adversely affected.

The osteopathic potential of diabetes has been documented. However, the effects of diabetes are confounded by many aspects of the conditions, ranging from differences inherent between type 1 and type 2 diabetes to the role of insulin in bone metabolism. The extrapolation of these concerns with bone metabolism and diabetes to dental implant therapy, while indirect, certainly supports caution.

Taken together, there are numerous studies that offer indirect evidence for diabetes patients to benefit from oral rehabilitation using dental implant therapy. There is also considerable evidence documenting compromises in bone metabolism associated with hyperglycemic conditions with the potential for these risks to mitigate benefits gained from implant therapy. Biologic studies suggest diabetes-related effects on bone metabolism; however, true differences in metabolic effects between type 1 and type 2 diabetes remain unclear. Similarly, the translation of results from hyperglycemic animal studies to patients remains to be elucidated. Further clarification of the impacts of diabetes and glycemic control with implant therapy in diabetic patients ultimately requires direct assessment provided through clinical investigations.

Diabetes and implant integration (based on the systematic search)

The goal of this systematic review is to critically evaluate clinical studies directly related to the use of dental implant therapy for patients with diabetes. As glycemic control is viewed primary to the application of implant therapy in patients with diabetes, this review further considers the evidence available specific to glycemic control as an indicator for implant therapy.

The majority of clinical investigations of implant survival identified in this review, 11 of 16 reports, were undertaken with the prevailing view that good glycemic control is critical to the successful use of implant therapy for patients with diabetes. All eleven of these studies only included patients considered as having acceptable glycemic control in order to receive implant therapy.

On closer evaluation of the documentation of glycemic control, 13 of the 16 studies identified were found to not meet methodologic completeness criteria for consideration of glycemic control (Table 1). This evaluation identified great variability in the way glycemic control was evaluated, reported or defined. Overall, eight of these studies did not report having a quantitative assessment of glycemic control (Shernoff, et al. 1994, Balshi & Wolfinger 1999, Fiorellini, et al. 2000, Morris, et al. 2000, Farzad, et al. 2002, van Steenberghe, et al. 2002, Peled, et al. 2003, Moy, et al. 2005). Several studies mentioned that the patients were well-controlled but did not report how this information was gained or how it was defined (Morris, et al. 2000, van Steenberghe, et al. 2002, Moy, et al. 2005). In some studies, patients were “encouraged” to have a good glycemic control and, for some patients, the diabetic status was determined by interview, but without any specific validation of these patient reports (Balshi & Wolfinger 1999, Farzad, et al. 2002). Further studies assessed the controlled diabetic status by means of glucose level testing (Fasting Plasma Glucose and 2-hour Postprandial Glucose) at one time point pre-operatively (Abdulwassie & Dhanrajani 2002) or 1 week before and after surgery and one time on the day of surgery (Peled, et al. 2003). While these tests have important diagnostic value, their ability to describe long-term levels of glycemic control is minimal, thus preventing these studies from discriminating effects of glycemic control on implant survival (see Table 1).

Evaluation of implant failure rates for these 13 studies demonstrated considerable variability in the rate of implant failure in patients with diabetes (0 to 14.3%; Figure 2). Additionally, the rate at which diabetic patients receiving one or more implants experienced at least one failed implant was highly variable (0 to 31.3%, Figure 2).

It is critical to our use of implant therapy in diabetic patients to recognize the lack of a clear definition of diabetes status and glycemic control in the interpretation of the results from these studies. This deficiency limits the application of their results toward the development of specific evidence-based guidelines for care for patients with diabetes. Additionally, in only 3 of these 13 studies was a comparative non-diabetic control population assessed (Morris, et al. 2000, Anner et al. 2010, Alsaadi et al. 2008a). Interestingly, consideration of the findings from these 3 of 13 studies also fails to demonstrate a difference in implant failure between diabetic (ranging from 2.8–7.8%) and non-diabetic patients (ranging from 1.9–6.8%). It is clear that these discordant results demonstrate our continuing need to clarify the parameters of diabetes impacting successful implant therapy.

The systematic search of the literature also identified 4 of the 16 studies in which patients lacking acceptable glycemic control were included, and 3 of these 4 studies in which all three methodologic components, i.e., methodology for assessments of glycemic control, as well as qualitative and quantitative stratifications of glycemic control, were considered (Tables 1 and 2).

In contrast to the studies lacking methodologic completeness, evaluation of the 3 recent studies meeting these methodologic criteria in reporting diabetes status of patients (Table 2) had implant failure rates ranging from 0 to 9.1%. These 3 reports extend the study of the effects of diabetes to clearly include patients having only moderate or poor glycemic control (Dowell, et al. 2007, Tawil, et al. 2008, Turkyilmaz 2010). The first of these studies evaluated implant healing over a 4 month evaluation period prior to implant restoration. Importantly, this study did so for diabetic patients having an HbA1c at the time of surgery up to 12% and with HbA1c levels extending as high as 13.8% over the 4 month evaluation period (Dowell, et al. 2007, Oates, et al. 2009). The 25 diabetes patients in this study included 12 patients (17 implants) who would not be considered as well-controlled, having HbA1c levels between 8.1–10.0%, and 3 patients (4 implants) with HbA1c levels over 10.0%. For all patients, this study failed to identify any implant failures over the initial 4-month healing period. However, consistent with animal studies of the effects of hyperglycemia on bone metabolism, this study did identify significant compromises in implant integration in direct relation to HbA1c levels (Oates, et al. 2009). Specifically, delays in implant integration were identified for patients having HbA1c levels over 8.0%, but not for patients below this level of glycemic control. This study's findings suggest that the effects of hyperglycemia on implant integration, if clinically significant, were successfully accommodated with the extended healing period from 2 months to 4 months prior to functional loading as utilized in this study.

In a second study, 45 diabetes patients having an initial HbA1c below 7.2% received 255 implants. They were followed over a period ranging from 1 to 12 years (Tawil, et al. 2008). The HbA1c levels for these patients varied over the follow-up period, with 44 patients recording HbA1c levels up to 9%, and 1 patient recording an HbA1c level over 9%. This latter patient received 11 implants and had one failure, giving the study its seemingly high failure rate (9.1% implant failure rate) for this level of glycemic control. However, when this patient's results are combined with the other 22 patients having only moderate glycemic control over the course of their evaluation period, the cumulative implant failure rate is 3.9%. As all these patients initiated implant therapy with an HbA1c <7.2% and the changes and duration of changes in HbA1c levels are unknown, the cumulative 2.9% failure rate for

all diabetic patients remains most relevant. This study is limited by the lack of clarity as to when the HbA1c levels were obtained for the patients during the follow-up period and when implant failures were identified. This study also failed to find a statistically significant difference in implant survival based on HbA1c levels, yet interestingly concluded that HbA1c is the most important factor affecting implant complication rate. Presumably, this conclusion is based on the trend observed in the study data, however patient numbers and limitations in HbA1c reporting as noted limit the value of this interpretation.

The third of these studies was a recent prospective case series of 10 patients with diabetes that included 4 patients having HbA1c levels between 8.1% and 10.0%. This study evaluated implant survival after 1 year of restoration and reported no implant failures (Turkyilmaz 2010).

Taken together, it appears that more recent studies of implant success with better-defined parameters of glycemic control support the use of dental implants for patients with diabetes mellitus, independent of glycemic status (Figure 3). It is important to note that while these studies were designed to examine the role for glycemic control in implant survival, these findings must be viewed as preliminary in that they include relatively small numbers of patients having elevated glycemic levels and offer only limited information on the longer term effects of diabetes on implant survival. It is also important to consider the potential for many other factors such as technologic advances in implant designs to enhance survival rates for implants in patients with diabetes. These preliminary findings do strongly support the continued exploration and translation of the effects of elevated glycemic levels in implant survival utilizing larger study populations and longer follow-up periods.

Conclusion

Oral health is an integral part of nutritional well-being and systemic health. Chronic diseases such as diabetes have oral sequelae that may lead to compromises in function, and oral function may importantly modulate dietary interventions critical to the overall management of diabetes (Touger-Decker & Mobley 2003). From a medical standpoint, there is no doubt that long-term good glycemic control is critical to the patient's minimizing diabetes related co-morbidities. However, good glycemic control may be dependent in part upon proper masticatory function. With diabetes contributing to oral pathologies and tooth loss, tooth replacement as can be provided with implant therapy may be an important contributor to the patient's overall well-being. Based on available literature to date, there are no clear clinical data supporting increased implant failures for patients lacking good glycemic control and, in fact, more recent studies support the use of dental implant therapy for patients in the absence of good glycemic control with appropriate accommodations for delays in implant integration. Therefore, with the potential benefit implant therapy has to offer, it may be in the diabetic patient's best interest to consider implant therapy, even in the absence of proper glycemic control. While this represents a shift in attitude toward diabetic patient care, it is one that requires careful consideration of both the risks and benefits of care, as well as our current limitations in our understanding of these relationships.

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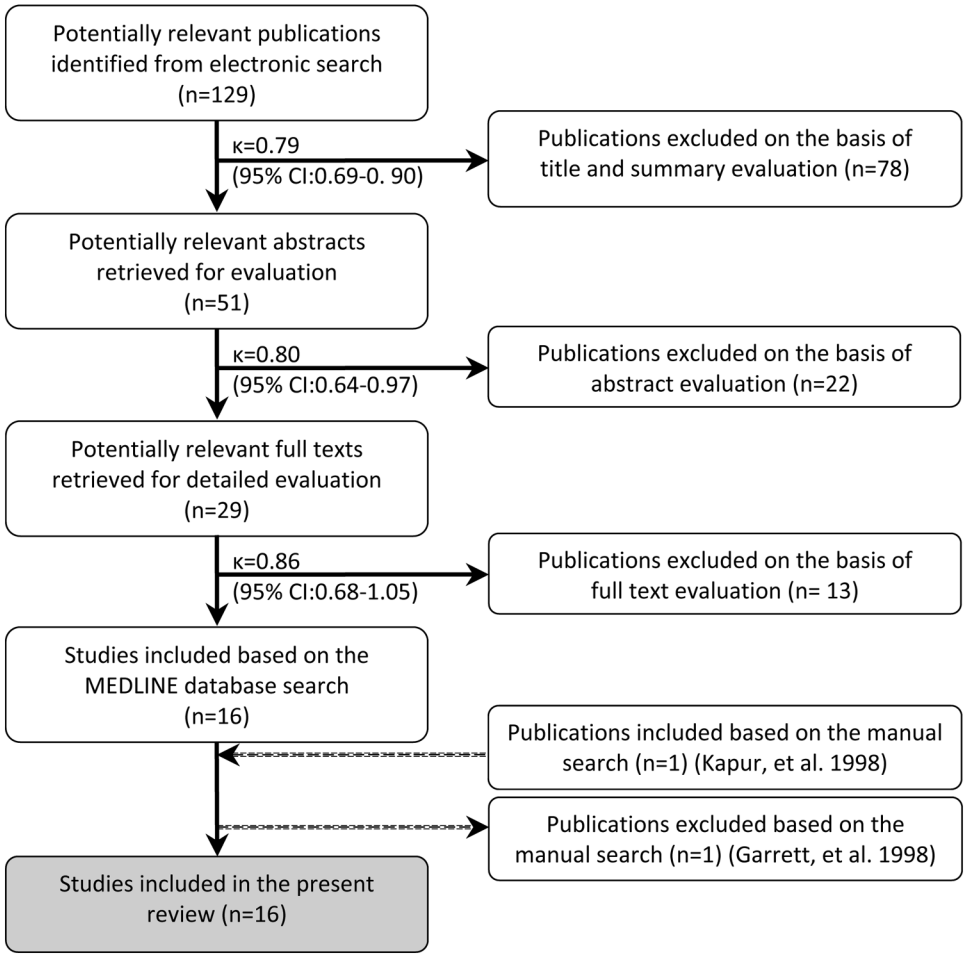

Figure 1.
Selection process of the included publications and inter-reviewer agreement measures

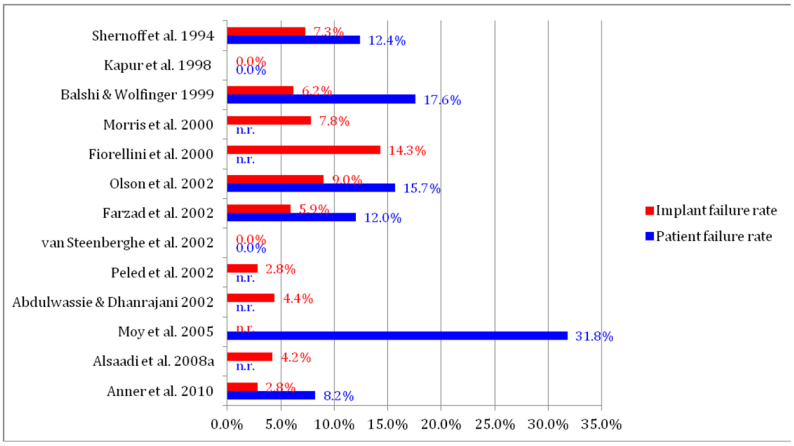

Figure 2.

Implant failure rate and patient failure rate (%) for studies on implant outcomes in patient with diabetes with partial information on level of glycemic control.
n.r.= not reported

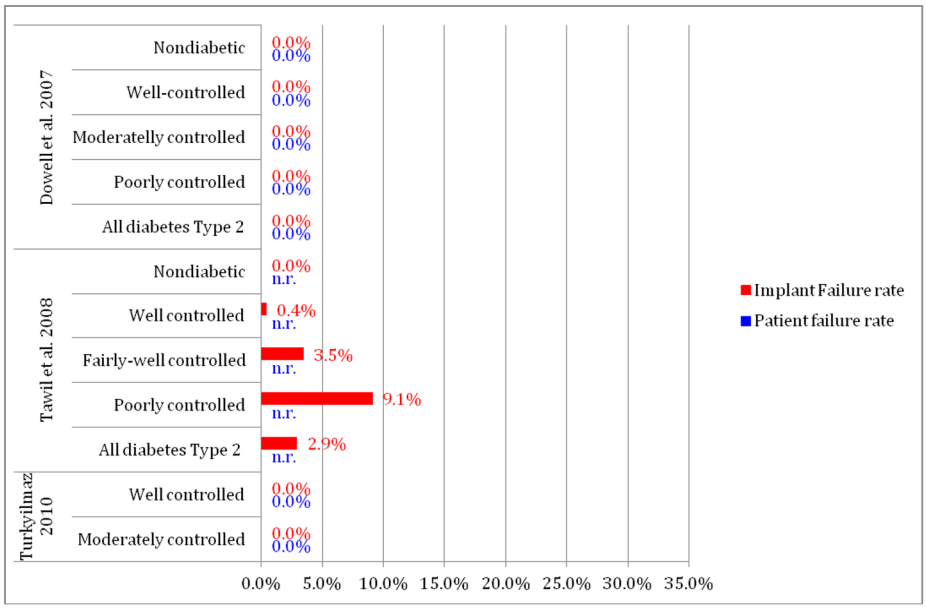

Figure 3.

Implant failure rate and patient failure rate (%) for studies on implant outcomes in patients with diabetes meeting glycemic control documentation criteria (including the report of the assessment method and the stratification of glycemic control from a qualitative and quantitative point of view)

n.r.= not reported

* represents 1 patient having 1 implant fail out of 11 placed

Table 1

nation on glycemic control

pe	Follow-up time	Patient Population	# of patients	# of implants	Glycemic Assessment	Qualitative glycemic control	Quantitative glycemic control	# of patient experiencing failure (rate)	# of implants failed (rate)	Findings and conclusions of the study
er prospective CS	1y	T2D	89	178	FPG HbA1c	acceptable	NR	11 (12.4%)	13 (7.3%)	"Implants can be considered for T2D patients"
ve CS	2y	T1D T2D	52	104	GHb	acceptable	mean 9.1%	0 (0.0%)	0 (0%)	"…implants can be successfully used…in DM patients with even low to moderate levels of metabolic control."
tive CS	NR	NR	34	227	Health history	controlled	NR	6 (17.6%)	14 (6.2%)	"…high success rate is achievable when dental implants are placed in DM patients whose disease is under control."
tive cohort	3y	ND T2D	NR	2632 ND 255 T2D	NR	NR	NR	NR	ND: 180 (6.8%) T2D: 20 (7.8%)	"…the use of endosseous dental implants for T2D patients involves a marginal risk to long-term implant survival."
er retrospective CS	mean 4y	T1D T2D	40	215	NR	controlled or uncontrolled	NR	NR	31 (14.3%)	"[no]… relationship between failure and… level of diabetic control…" AND "… implants… in

pe	Follow-up time	Patient Population	# of patients	# of implants	Glycemic Assessment	Qualitative glycemic control	Quantitative glycemic control	# of patient experiencing failure (rate)	# of implants failed (rate)	Findings and conclusions of the study
										well-controlled DM patients… reduced success and survival…”
er prospective CS	5y	T2D	89	178	FP, HbA1c (normal not defined)	controlled to uncontrolled	FPG=154mg/dl HbA1c: normal or above	14 (15.7%)	16 (9.0%)	“…degree of diabetic control…did not make a significant difference in implant outcome.” “… endosseous dental implants… for…T2D patients… predictable procedure.”
tive CS	1y	T1D T2D	25	136	Health history	well-controlled	NR	3 (12.0%)	8 (5.9%)	“ Diabetics that undergo dental implant treatment do not encounter higher failure rate than the normal population if the patients’ plasma glucose level is normal or close to normal…”
ve CS	NR	T1D T2D	NR	~ 30	NR	controlled	NR	0 (0.0%)	0 (0%)	“…controlled T1D and T2D…did not lead to an increased incidence in the early-failure group.”

pe	Follow-up time	Patient Population	# of patients	# of implants	Glycemic Assessment	Qualitative glycemic control	Quantitative glycemic control	# of patient experiencing failure (rate)	# of implants failed (rate)	Findings and conclusions of the study
ve CS	3y	T2D	41	141	FP 2hPPG	well-controlled	NR	NR	4 (2.8%)	"…dental implants can be used in DM patients if…proper patient selection and… diabetes is well controlled."
ve CS	NR	NR	25	113	FPG	controlled	≤126 mgl/dl	NR	5 (4.4%)	"Dental implants can be used successfully in patients who are diabetic provided that blood sugar levels are under control"
tive CS	≤21 y	NR	48	NR	NR	adequate	NR	15 (31.8%)	NR	"Significantly increased failure rates were seen in …diabetics."
ve CS	up to loading	ND T2D	283	682 ND 24T2D	NR	controlled	NR	NR	ND: 13 (1.9%) T2D: 1 (4.2%)	"Certain factors, such as… Controlled T2D, …did not lead to an increased incidence in the early failures."
tive cohort	mean 30.8m	NR	426 ND 49 DM	1449 ND 177 DM	NR	controlled	NR	ND: 54 (12.7%) DM:4 (8.2%)	ND: 72 (5.0%) DM: 2 (2.8%)	"This study found no evidence of diminished clinical success or significant early healing complications associated

Author, Year	Follow-up time	Patient Population	# of patients	# of implants	Glycemic Assessment	Qualitative glycemic control	Quantitative glycemic control	# of patient experiencing failure (rate)	# of implants failed (rate)	Findings and conclusions of the study
										with implant therapy in patients with controlled T2D."

controlled trial; ND=non-diabetic; DM=diabetes mellitus; T1/2D=type 1/2 diabetes; NR=not reported; GHB=Total glycated hemoglobin [9.1%=[est]HbA1c 7.5–8.1%]

Table 2

ycemic control documentation criteria (including the report of the assessment method and the stratification of glycemic control from a ntitative point of view)

udy type	Follow-up time	Patient Population	# of patients	# of implants	Method for glycemic control assessment	Qualitative glycemic control	Quantitative glycemic control (HbA1c%)	# of patients	# of implants	# of patient experiencing failure (rate)	# of implants failed (rate)	Findings and conclusions of the study
ospective cohort	4m	ND T2D	10 ND 25 T2D	11 ND 39 T2D	HbA1c	ND	< 6	10	12	0 (0.0%)	0 (0%)	" …no evidence of diminished clinical success or significant early healing complications associated with implant therapy based on the glycemic control levels of patients with T2D."
						Well	6.0–8.0	10	17	0 (0.0%)	0 (0%)	
						Moderate	8.1–10.0	12	17	0 (0.0%)	0 (0%)	
						Poor	> 10.0	3	4	0 (0.0%)	0 (0%)	
ospective cohort	mean 42.4m (1–12 y)	ND T2D	45 ND 45 T2D	244 ND 255 T2D	FPG HbA1c	ND	NR	45	244	NR	1 (0.4%)	" Well-to fairly well-controlled DM patients…had the same overall survival rates as controls…" "…6 of 7 failures occurred [within] first year…" Note: study did include immediate loading of some implants. "HbA1c is the most important factor affecting implant
						Well	< 7.0	22	103	NR	1 (1.0%)	
						Moderate	7.0–9.0	22	141	NR	5 (3.5%)	
						Poor	> 9.0	1	11	NR	1 (9.1%)	
						All T2D	-	45	255	NR	7 (2.9%)	

udy type	Follow-up time	Patient Population	# of patients	# of implants	Method for glycemic control assessment	Qualitative glycemic control	Quantitative glycemic control (HbA1c%)	# of patients	# of implants	# of patient experiencing failure (rate)	# of implants failed (rate)	Findings and conclusions of the study
												complication rate.”
ospective CS	1 y	T2D	10	23	HbA1c	Well	<8.0	6	15	0 (0.0%)	0 (0%)	“ …dental implant treatment can be offered to patients with well or moderately controlled T2D.”
						Moderate	8.1–10.0	4	8	0 (0.0%)	0 (0%)	

-diabetic; DM=diabetes mellitus; T2D=type 2 diabetes; NR=not reported