Safety and feasibility of immediate implant placement in diabetic patients: A systematic review and meta-analysis

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Abstract. The increasing use of dental implants raises questions about their efficacy in diabetic patients, particularly for immediate implant placement (IIP). Well-controlled diabetic patients may achieve success rates comparable with healthy individuals. To the best of our knowledge, however, comprehensive meta-analyses on IIP outcomes in diabetics remain limited. The present study aimed to judge whether IIP could be adopted in diabetic patients. A systematic search was conducted in PubMed, Embase, Web of Science, Cochrane, Google Scholar and China National Knowledge Infrastructure databases (January 2000 to March 2025). Studies comparing implant survival rates (SR), marginal bone loss (MBL), probing depth (PD) and bleeding on probing (BOP) between diabetic (well-/poorly controlled) and healthy patients undergoing IIP were included. The methodological quality and risk of bias of the included studies were assessed using the Newcastle-Ottawa Scale. Meta-analysis was performed using RevMan 5.4 software to calculate mean difference (MD) and risk ratio (RR) with 95% confidence interval (CI). A random-effects model was employed to address heterogeneity. A total of 10 studies (1,350 patients, 1,623 implants) were included in the analysis, demonstrating moderate to high methodological quality overall. Compared with healthy patients, well-controlled diabetic patients showed no significant difference in SR (RR=1.00, 95% CI: 0.97-1.02, P=0.79); similarly, poorly controlled diabetic patients also exhibited SR comparable with what of healthy patients (RR=0.96, 95% CI: 0.88-1.06, P=0.47). However, well-controlled diabetic patients had significantly higher MBL than healthy patients (MD=0.08, 95% CI: 0.03-0.14, P=0.004), while poorly-controlled diabetic patients showed greater MBL (MD=0.39, 95% CI: 0.25-0.53, P<0.00001). Additionally, well-controlled diabetic patients showed no significant difference in PD compared with healthy patients (MD=0.17, 95% CI: -0.02-0.37, P=0.09), but had significantly higher BOP (MD=0.12, 95% CI: 0.07-0.17, P<0.00001). Poorly-controlled diabetic patients demonstrated significantly higher PD (MD=0.62, 95% CI: 0.38-0.86) and BOP (MD=0.24, 95% CI: 0.23-0.24; both P<0.00001). There was notable heterogeneity among studies included in the meta-analysis and individual studies may influence the overall findings. Despite these limitations, the present results suggested that for diabetic patients, particularly those with optimal glycemic control, IIP demonstrates comparable implant SR with healthy individuals, confirming its clinical feasibility. However, diabetic patients, especially those with poor glycemic control, face increased risks of peri-implant bone loss and inflammation. Strict preoperative glycemic management and diligent postoperative care are key to minimize complications and ensure long-term implant SR.

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Introduction

Dental implants have become one of the primary methods for tooth replacement and have gained widespread global application in recent years (1-3). Compared with traditional restorative methods, implant-supported restorations not only markedly improve masticatory function, speech, and comfort but also enhance aesthetic outcomes, Patients achieve higher satisfaction in these parameters, including an overall aesthetic satisfaction rate of 96.67% (4-10). Furthermore, implant-supported restorations boost patient self-confidence and life quality (11,12). As a result, dental implant rehabilitation has become the preferred method for tooth replacement in modern dentistry. The survival rate (SR) of dental implants is associated with osseointegration; successful osseointegration is influenced by multiple factors, including implant design, surgical technique, systemic metabolic status and immune function (13). Diabetic patients, due to metabolic dysregulation, may experience secondary vascular and bone tissue complications, which interfere with osseointegration and long-term implant stability, increasing the risk of peri-implantitis (14). Additionally, microvascular complications in diabetic patients may decrease the release of repair cells and growth factors, impair collagen synthesis and hinder soft tissue regeneration (1). Consequently, diabetic patients are typically considered unsuitable for implant rehabilitation (4,15).

Diabetes mellitus (DM) has seen a notable increase in prevalence over the past decades, with the number of affected individuals worldwide exceeding 800 million (16). Diabetic patients typically exhibit poorer oral health, with a markedly higher prevalence of edentulism compared with non-diabetic populations. Adults with diabetes exhibit approximately twice the tooth loss rate as those without diabetes (17). This disparity is primarily attributed to their increased susceptibility to oral disease, such as periodontitis and dental caries, and experience accelerated alveolar bone resorption following tooth loss (14,18,19). As a result, implant-supported restorations have become a key option for diabetic patients to restore masticatory function and improve life quality. Well-controlled diabetic patients do not experience a significant decrease in implant SR following implant placement (20,21) For example, Diehl *et al* (22) observed that implant SR reached 100% in both diabetic and normoglycemic groups, with no significant differences in probing depth (PD), marginal bone loss (MBL), and bleeding on probing (BOP). Similarly, Tulbah *et al* (23) conducted a 5-year follow-up study and observed that, despite a higher incidence of complications in diabetic patients, implant SR did not markedly decline, further supporting the hypothesis that diabetic patients can achieve long-term implant success. These findings have led to the increasing application of implant-supported restoration in the dental treatment of diabetic patients (24,25).

Research on implant rehabilitation in diabetic patients has primarily focused on delayed implant placement strategies. Most studies indicate that, with well-controlled blood glucose levels, the implant SR in diabetic patients is comparable with those in non-diabetic patients (26,27). However, rapid alveolar bone resorption following tooth extraction may lead to insufficient bone volume, necessitating bone augmentation procedures, which not only increase surgical risk but also impose additional financial burdens on patients (8,28-30). Moreover, the extended treatment duration may compromise masticatory efficiency, negatively impacting patient quality of life. Compared with delayed implantation, immediate implant placement (IIP) simplifies the repair process by placing implants during tooth extraction, reducing the number of surgeries and overall waiting time for the final prosthesis. In addition, this method helps to maintain the size of the alveolar ridge, thereby supporting the overlying soft tissue (31-34). To date, there is limited research on IIP in diabetic patients, and existing meta-analyses exhibit limitations (35). For example, Andrade *et al* (35) found no significant differences in implant SR between diabetic and healthy individuals. However, the aforementioned meta-analysis included seven studies, with only five being utilized for quantitative synthesis. In the analysis of MBL, the comparison was limited to immediate vs. conventional loading in diabetic patients, without a thorough exploration of differences compared with healthy patients. Additionally, key soft tissue indicators such as probing depth (PD) and BOP were not analyzed. In conclusion, the limitations of existing meta-analyses include a small number of included studies, incomplete observation indicators and a lack of comprehensive evaluation of both hard and soft tissue health. It was hypothesized that IIP could be applied in diabetes patients. The present study aimed to determine whether IIP could be adopted in diabetic patients by assessing its feasibility and safety in diabetic patients.

Materials and methods

Data retrieval and collection. According to the Population/Patient, Intervention; C: Comparison; O: Outcome principle, PubMed (https://pubmed.ncbi.nlm.nih.gov), Embase (embase.com), Web of science (https://www.webofscience.com), Cochrane (https://www.cochranelibrary.com), Google (scholar.google.com) and China National Knowledge Infrastructure (CNKI) (https://www.cnki.net) databases were searched from January 2000 to March 2025. Key words were as follows: 'Diabetic patients' or 'DM' or 'type 2 diabetes' or 'glycemic control' or 'hyperglycemia' and 'IIP' or 'immediate dental implant' or 'immediate implant restoration' or 'immediate loading' and 'healthy patients' or 'non-diabetic patients' or 'systemically healthy' and 'implant survival rate' or 'implant success rate' or 'implant failure' or 'MBL' or 'bone resorption' or 'peri-implant bone level' or 'PD' or 'peri-implant probing depth' or 'BOP' or 'peri-implant bleeding' or 'safety' or 'complications' or 'adverse events'.

Inclusion criteria were as follows: i) Studies involving diabetic (including those with well- and poorly controlled diabetes) and healthy patients who underwent IIP for single or multiple teeth (age, ≥18 years); ii) intervention measure is IIP, with healthy patients serving as the control group receiving the same intervention; iii) studies that reported key outcome measures such as implant SR, MBL, PD, BOP or complications, with a follow-up period ≥6 months.

Exclusion criteria were as follows: i) Case reports, reviews and meta-analyses; ii) animal-related research; iii) studies with a sample size <10; and iv) studies with incomplete data.

Data extraction. A total of two independent researchers systematically performed the literature screening and data extraction according to the inclusion/exclusion criteria. Titles and abstracts were screened, followed by full-text assessment of eligible studies. Discrepancies between the two researchers were resolved through discussion, and if consensus could not be reached, a third senior researcher was consulted. Extracted data included first author, year of publication, study design, number of patients and implants, follow-up time and outcome measures such as MBL, PD, BOP and SR. The follow-up durations were categorized into three subgroups according to the time points available in the included studies: ≤6 months, 12 and ≥24 months, representing short-term, mid-term, and long-term follow-up, respectively.

Quality evaluation of included literature. Newcastle-Ottawa Scale (NOS) was adopted to evaluate the quality of literature (36).

Statistical analysis. Meta-analysis was conducted using RevMan 5.4 software (cochranelibrary.com/). For continuous variables (MBL, PD and BOP), the mean difference (MD) and 95% confidence interval (CI) were calculated. For dichotomous variables (implant SR), the risk ratio (RR) and 95% CI were determined. Heterogeneity between studies was assessed using the Cochrane Q test and the I^2 statistic, with

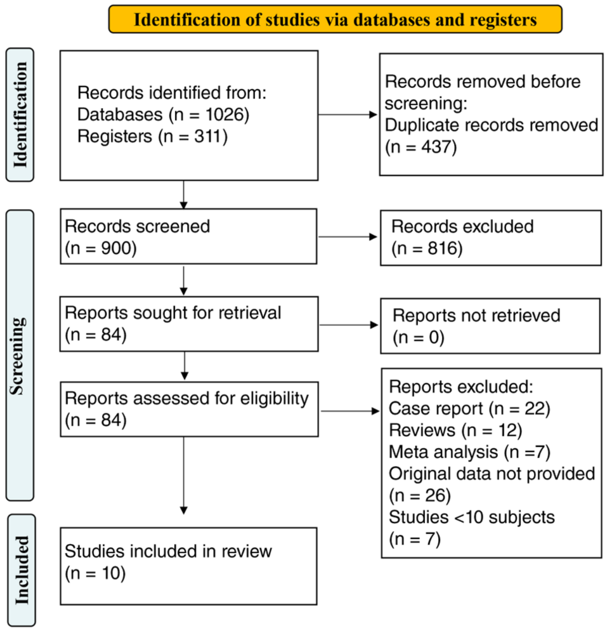

Figure 1. Flow chart for data retrieval.

$I^2 \geq 50\%$ indicating substantial heterogeneity, in which case a random-effects model was applied. Subgroup analyses were performed based on glycemic control levels in diabetic patients and follow-up duration. Sensitivity analysis was performed using the leave-one-out method. Publication bias was assessed using a funnel plot. $P<0.05$ was considered to indicate a statistically significant difference.

Results

Study characteristics. A total of 1,337 relevant studies were initially retrieved. After removing 437 duplicate records, 900 studies remained. Title and abstract screening excluded 816 studies. The full text of the remaining 84 studies was further reviewed, leading to the exclusion of 74 studies. A total of 10 studies meeting the eligibility criteria were included (Fig. 1) (37-46). Among the 10 included studies, most had a follow-up period ranging from 6 to 24 months (37,39-41,43,45,46), while some extended to 10 and 15 years (38,44). The sample sizes varied from 23 patients (168 implants) to 655 patients (922 implants). Implant placement approaches included single-tooth restoration, full-arch rehabilitation and the all-on-four concept, though some studies did not specify detailed implant strategies (40,44). The methodological quality was assessed using the NOS. The median Ottawa score was 7 (range, 6-9), indicating that the overall quality of the included studies was high (Table I).

Implant SR between diabetic and healthy patients. No significant difference was observed in implant SR between well-controlled diabetic patients and healthy individuals (RR=1.00, 95% CI: 0.97-1.02), with moderate heterogeneity among studies ($I^2=36\%$). Similarly, no significant decrease in implant SR was observed in poorly controlled diabetic patients (RR=0.96, 95% CI: 0.88-1.06), although heterogeneity was relatively high ($I^2=54\%$; Fig. 2). In well-controlled diabetic patients, individual studies consistently showed implant SR comparable with those of healthy individuals (RR: 0.96-1.01) (38-44), with no significant differences. In poorly controlled diabetic patients, individual studies reported similar implant SR to healthy individuals (RR range: 0.86-1.00) (39,40,44), with no significant differences. Although the overall implant SR did not differ markedly between diabetic patients and healthy individuals, the pooled effect size for poorly controlled diabetic patients was lower than that for healthy individuals (RR=0.96), suggesting that glycemic control impacts implant SR.

Diabetic patients undergoing IIP have higher MBL. Well-controlled diabetic patients exhibited higher MBL than healthy individuals (MD=0.07, 95% CI: 0.02-0.12). Poorly controlled diabetic patients showed a more pronounced increase in MBL (MD=0.39, 95% CI: 0.25-0.53). Subgroup analysis indicated that in poorly controlled diabetic patients, MBL was significantly higher at all time points (≤6, 12 and ≥24 months; Fig. 3). Although well-controlled diabetic patients exhibited higher MBL than healthy individuals, this was not significant in any individual follow-up subgroup but achieved statistical significance in the pooled overall analysis, likely because of the increased statistical power from combining the subgroups. Among well-controlled diabetic patients, Aguilar-Salvatierra (39) and Al Amri (40) reported markedly higher MBL compared with healthy individuals, whereas other studies found no significant difference (37,43,45,46). In poorly controlled diabetic patients, all studies consistently showed markedly greater MBL than in healthy individuals. High heterogeneity was observed in MBL analyses ($I^2=73-97\%$). Despite the notable heterogeneity, the results from the random-effects model consistently supported the conclusion that diabetic patients, especially those with inadequate glycemic control, experience markedly greater MBL following IIP.

Diabetic patients undergoing IIP experience greater PD. No significant difference was observed in PD between well-controlled diabetic patients and healthy individuals (MD=0.17, 95% CI: -0.02-0.37). However, poorly controlled diabetic patients exhibited significantly greater PD than healthy individuals (MD=0.62, 95% CI: 0.38-0.86). Subgroup analysis revealed that in poorly controlled diabetic patients, PD was significantly higher at all time points (≤6, 12 and ≥24 months; Fig. 4). In well-controlled diabetic patients, although PD was slightly higher than in healthy individuals, the difference was significant only in a few individual studies (39,40). Among well-controlled diabetic patients, Al Amri (40) reported markedly higher PD than in healthy individuals, while other studies found no significant difference (37,45). In poorly controlled diabetic patients, both Aguilar-Salvatierra (39) and Al Amri (40) reported markedly greater PD compared with healthy individuals. High heterogeneity was observed in PD analyses ($I^2=96-97\%$). Despite the notable heterogeneity, the results from the random-effects model consistently supported the conclusion that poorly controlled diabetic patients experienced markedly greater PD following IIP.

Table I. Basic information and relevant efficacy indicators of included studies.

		Patients/total implants				Marginal bone loss, mm			Probing depth, mm			Bleeding on probing, %			Survival rate			
First author, year	Study design	Poorly controlled DM	Well-controlled DM	Healthy	Follow-up time, months	Poorly controlled DM	Well-controlled DM	Healthy	Poorly controlled DM	Well-controlled DM	Healthy	Poorly controlled DM	Well-controlled DM	Healthy	Poorly controlled DM	Well-controlled DM	Healthy	NOS score
Agliardi *et al*, 2023 (38)	RCS	NR	19/76	154/616	180	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	71/76	602/616	6
Aguilar-Salvatierra *et al*, 2016 (39)	PCS	22/22	30/30	33/33	6	1.33±0.29	0.71±0.31	0.51±0.19	3.43±0.23	2.54±0.32	2.43±0.25	0.59±0.07	0.41±0.04	0.36±0.06	19/22	28/29	33/33	8
					12	1.54±0.43	0.86±0.25	0.64±0.23	3.57±0.37	2.66±0.27	2.60±0.18	0.65±0.06	0.45±0.07	0.39±0.04	NR	NR	NR	
					24	1.92±0.38	0.98±0.27	0.72±0.27	3.68±0.48	2.79±0.24	2.67±0.14	0.74±0.05	0.51±0.05	0.44±0.07	NR	NR	NR	
Al Amri *et al*, 2016 (40)	PCS	31/31	30/30	30/30	6	0.55±0.06	0.52±0.02	0.33±0.11	3.30±0.21	2.50±0.18	2.00±0.50	0.71±0.05	0.63±0.06	0.42±0.05	31/31	30/30	30/30	8
					12	0.57±0.07	0.54±0.12	0.45±0.06	2.40±0.35	2.30±0.26	1.90±0.04	0.63±0.02	0.60±0.04	0.40±0.02	NR	NR	NR	
					24	0.59±0.20	0.58±0.15	0.46±0.16	2.30±0.62	2.30±0.15	1.60±0.05	0.62±0.05	0.62±0.07	0.40±0.06	NR	NR	NR	
Alves *et al*, 2010 (41)	PCS	NR	4/28	19/140	36	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	28/28	138/140	6
Bell *et al*, 2011 (42)	RCS	NR	23/83	632/839	3-93	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	83/83	824/839	6
D'Orto *et al*, 2022 (43)	RCS	NR	22/114	25/122	6	NR	0.63±0.54	0.57±0.52	NR	NR	NR	0.62±0.06	0.52±0.06	0.43±0.05	NR	108/114	118/122	8
					12	NR	0.94±0.75	0.99±0.82	NR	NR	NR	0.63±0.07	0.54±0.06	0.47±0.05	NR	NR	NR	
					24	NR	0.82±0.64	0.84±0.73	NR	NR	NR	0.72±0.06	0.56±0.07	0.45±0.06	NR	NR	NR	
					36	NR	0.90±0.76	0.86±0.79	NR	NR	NR	NR	NR	NR	NR	NR	NR	
Gómez-Moreno *et al*, 2015 (37)	PCS	22/22	24/24	21/21	12	0.54±0.12	0.45±0.15	0.41±0.18	2.23±0.28	2.24±0.20	2.19±0.22	NR	NR	NR	NR	NR	NR	8
					24	0.63±0.16	0.52±0.18	0.48±0.15	2.37±0.26	2.27±0.23	2.21±0.20	NR	NR	NR	NR	NR	NR	
					36	0.70±0.19	0.57±0.16	0.53±0.17	2.40±0.25	2.30±0.23	2.26±0.19	NR	NR	NR	NR	NR	NR	
Han *et al*, 2021 (45)	RCS	15/15	15/15	30/30	3	NR	NR	NR	2.55±0.51	1.65±0.46	1.71±0.27	NR	NR	NR	NR	NR	NR	7
					6	NR	NR	NR	2.33±0.51	1.72±0.44	1.76±0.20	NR	NR	NR	NR	NR	NR	
Tawil *et al*, 2008 (44)	PCS	1/11	10/47	12/59	12-144	NR	NR	NR	NR	NR	NR	NR	NR	NR	11/11	47/47	58/59	7
Zhao *et al*, 2022 (46)	RCS	NR	21/24	135/161	6	NR	0.68±0.38	0.77±0.31	NR	NR	NR	NR	NR	NR	NR	NR	NR	8
					12	NR	0.97±0.39	1.09±0.49	NR	NR	NR	NR	NR	NR	NR	NR	NR	
					24	NR	1.10±0.39	1.23±0.54	NR	NR	NR	NR	NR	NR	NR	NR	NR	

RCS, retrospective cohort study; PCS, prospective cohort study; NOS, Newcastle-Ottawa scale; DM, diabetes mellitus; NR: not reporte.

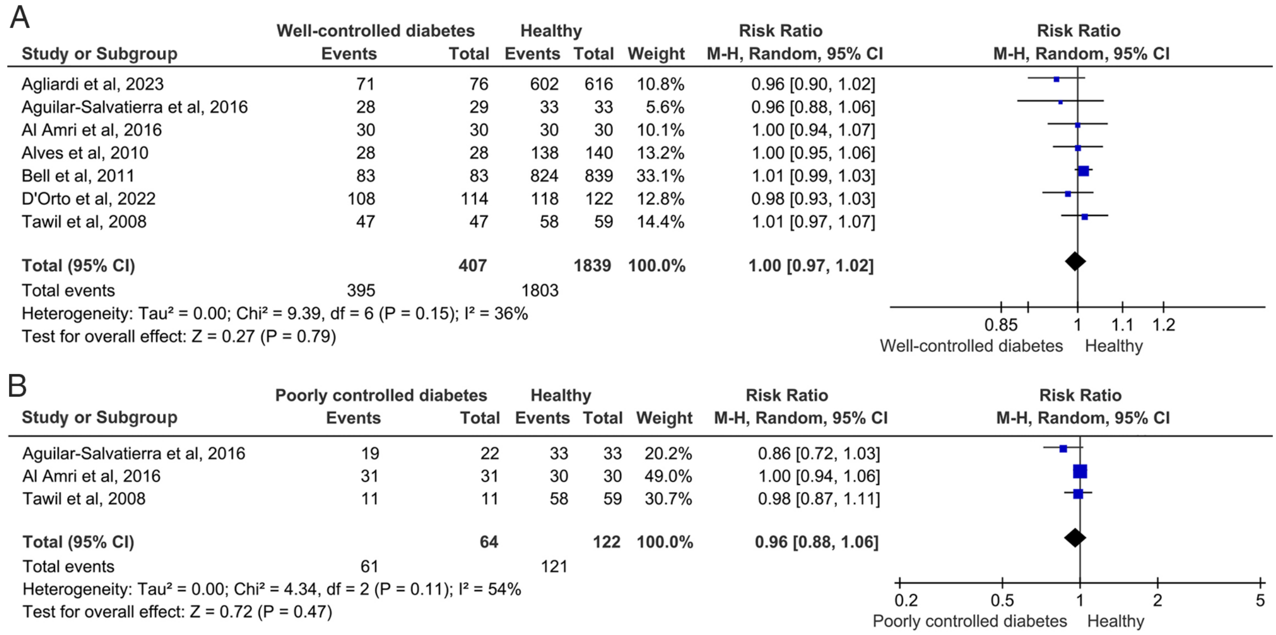

Figure 2. Implant survival rate in diabetic patients compared with healthy individuals. (A) Well- and (B) Poorly controlled diabetic patients vs. healthy individuals. M-H, Mantel-Haenszel.

Diabetic patients undergoing IIP experience higher BOP. Well-controlled diabetic patients exhibited significantly higher BOP than healthy individuals (MD=0.12, 95% CI: 0.07-0.17); poorly controlled diabetic patients also exhibited a significant increase in BOP compared with healthy individuals (MD=0.23, 95% CI: 0.21-0.26). Subgroup analysis revealed that in poorly controlled diabetic patients, BOP was markedly higher at all time points (≤6, 12 and ≥24 months; Fig. 5). In well-controlled diabetic patients, while BOP was also higher than in healthy individuals, the difference was significant only at 12 and ≥24 months. A high degree of heterogeneity was observed in the BOP forest plot (I^2=88-97%). Despite the notable heterogeneity, the results from the random-effects model consistently supported the conclusion that diabetic patients, particularly those with inadequate glycemic management, experience markedly higher BOP following IIP.

Safety. A total of two studies (42,43) compared the incidence of complications following immediate implant placement, primarily focusing on edema, bleeding and wound infection. The results indicated no significant increase in complication rates compared with healthy patients (data not shown).

Sensitivity analysis. To evaluate the robustness of the meta-analysis results, sensitivity analysis was performed using the leave-one-out method. The pooled effect size and 95% CI remained stable across all iterations, indicating that the findings were not notably influenced by any single study (data not shown). For example, in the analysis of implant SR, the exclusion of Agliardi *et al* (38) yielded a RR of 1.01 (95% CI: 0.90-1.02) for well-controlled diabetic patients. Similarly, the exclusion of Aguilar-Salvatierra (39) resulted in an RR of 1 (95% CI: 0.97-1.02). These results were consistent with the overall pooled effect size (RR=1, 95% CI: 0.97-1.02). The stability of the effect estimates across all sensitivity analyses underscored the robustness of the meta-analysis findings and suggests that the results are not driven by any individual study.

Publication bias. To assess the potential publication bias, funnel plot analysis was performed for the outcomes of SR, MBL, PD and BOP. Visual inspection of the funnel plots for SR, MBL, PD and BOP revealed a symmetrical distribution (Fig. 6), indicating no apparent publication bias. This suggested that the results of the meta-analysis are not markedly influenced by publication bias and have high reliability.

Discussion

IIP offers the advantages of decreasing treatment duration, minimizing the number of surgical procedures and maintaining the contour of the alveolar ridge. This is beneficial in the maxillary anterior region, where good soft tissue profiles and aesthetic outcomes can be achieved (31,32). However, IIP demands high initial stability; patients with acute infection, severe bone defect or high occlusal loads may face increased risk of early failure (33,34). By contrast, delayed implantation is typically performed 3-6 months after tooth extraction, allowing healing of the extraction socket and sufficient bone regeneration before implant placement. This approach improves the success rate of osseointegration and long-term stability. However, delayed implantation results in a longer treatment timeline, requiring patients to wear temporary dentures, which may affect chewing efficiency and life quality and increase psychological burden (47-50). For diabetic patients, particularly those with well-controlled diabetes, the question of whether IIP can be performed is a key issue in clinical practice. The present meta-analysis demonstrated no obvious difference was in implant SR between diabetic patients and healthy individuals who undergo IIP. However, obvious differences were observed between in terms of MBL,

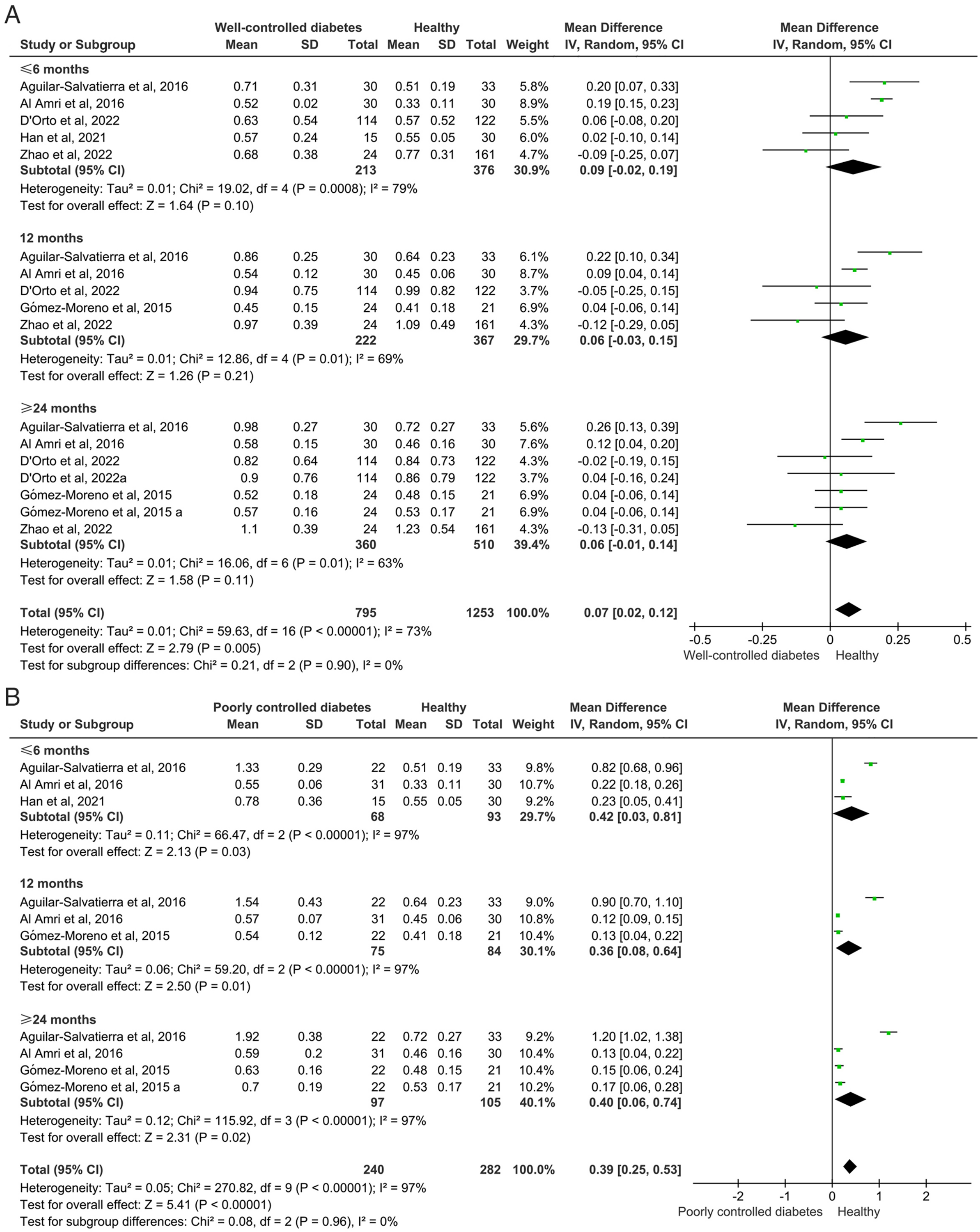

Figure 3. Marginal bone loss in diabetic patients compared with healthy individuals, stratified by follow-up duration. (A) Well- and (B) Poorly controlled diabetic patients. IV, inverse variance.

PD and BOP Diabetic patients, particularly those with inadequate glycemic management, exhibited worse outcomes.

The primary evaluation criterion for survival in the present study was implant retention. The present findings indicated that, when glycemic control was good, implant SR did not differ markedly between diabetic patients and healthy individuals. Although hyperglycemia can affect the blood supply to the implant area, impair soft and bone tissue healing

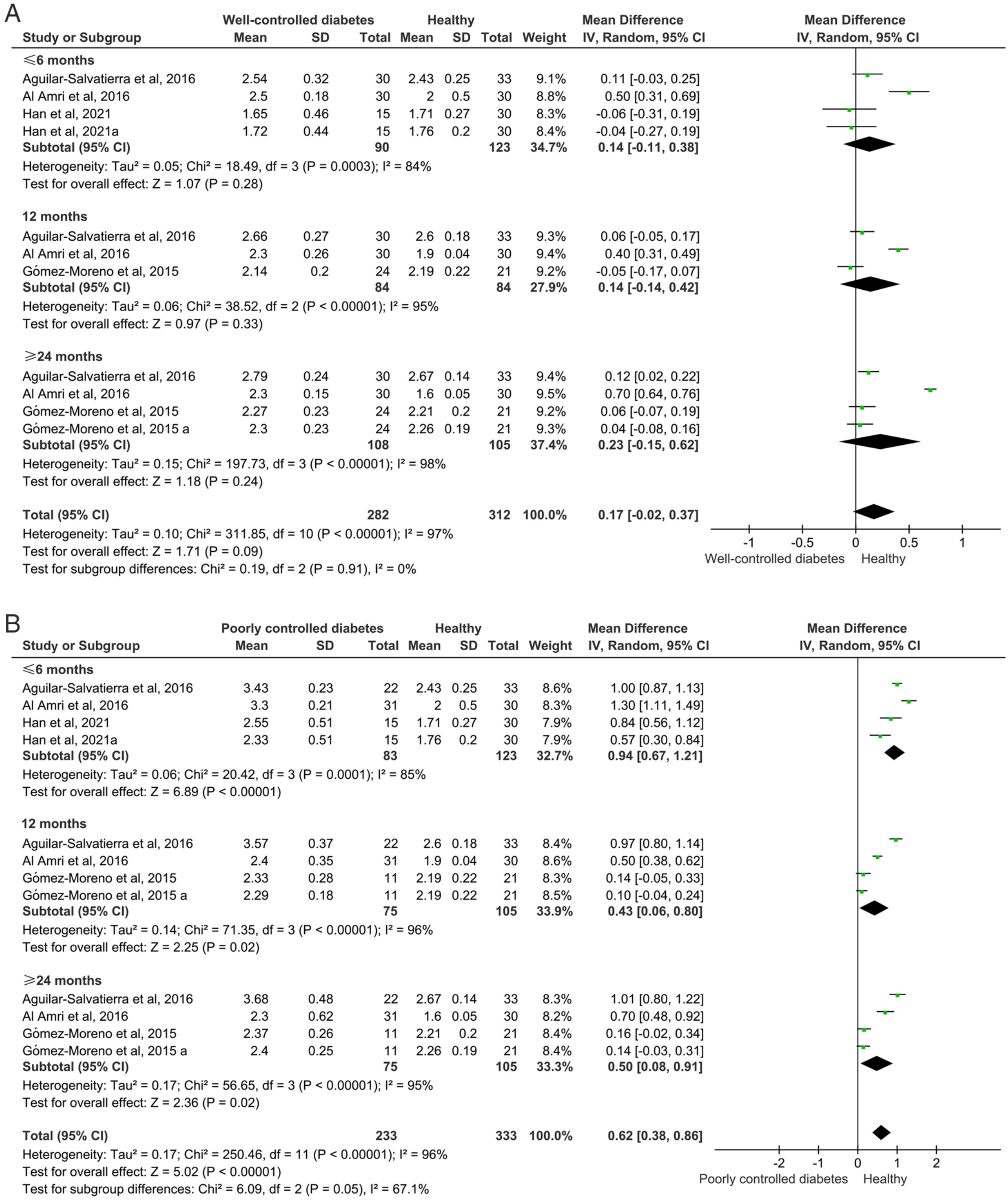

Figure 4. Forest plots of implant probing depth in diabetic patients compared with healthy individuals, stratified by follow-up duration. (A) Well-and (B) Poorly controlled diabetic patients vs. healthy individuals at ≤6, 12, and ≥24 months.. IV, Inverse variance.

and increase the risk of peri-implantitis, maintaining strict blood sugar control and enhancing oral hygiene guidance improve long-term implant success (40,51-53). However, the present results also showed that diabetic patients with poor glycemic control did not experience a markedly lower SR compared with healthy individuals, which is inconsistent with current research. Ayele *et al* (54) provided further evidence on the impact of diabetes on implant survival, indicating that uncontrolled type 2 DM leads to increased peri-implant bone loss and decreased implant SR. The discrepancy in the present study may be attributed to the fact that Tawil *et al* (44) only enrolled one patient with poorly controlled blood sugar, who received 11 implants, all of which remained intact. Al Amri *et al* (40) reported that all patients had a 100% implant

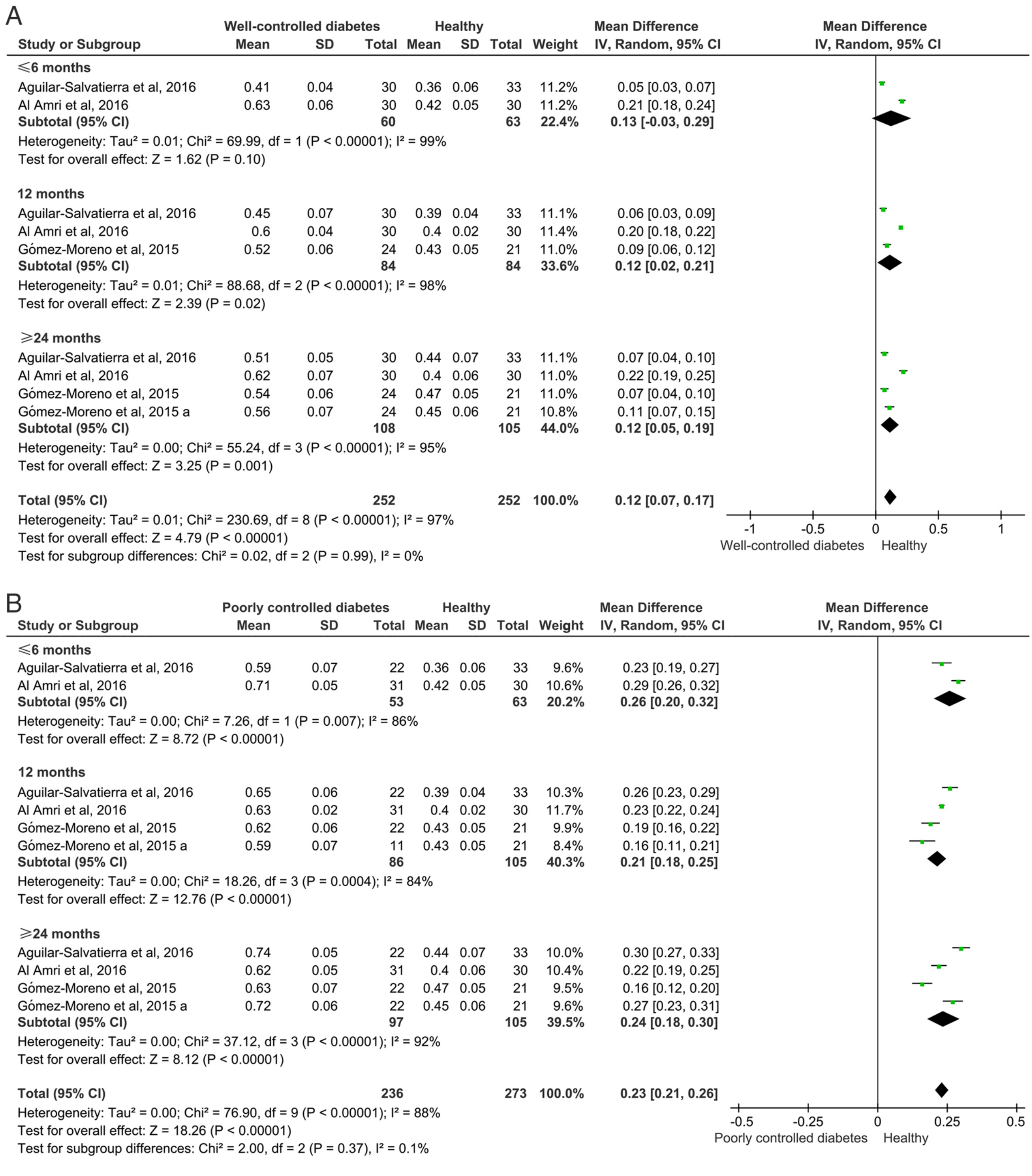

Figure 5. Forest plots of implant bleeding on probing in diabetic patients compared with healthy individuals, stratified by follow-up duration. (A) Well- and (B) Poorly controlled diabetic patients vs. healthy individuals at ≤6, 12, and ≥24 months. IV, Inverse variance.

SR during the follow-up period, resulting in consistent data. Aguilar-Salvatierra *et al* (39) reported that diabetic patients with high hemoglobin A1c (HbA1C) levels initially showed good glycemic control, with HbA1C levels markedly decreasing after 24 months follow-up. Therefore, satisfactory blood sugar control in diabetic patients following IIP is a key factor influencing implant SR.

Diabetes may induce secondary vascular and osseous complications, which interfere with the osseointegration of implants. This affects the success rate of implants and the healing of peri-implant bone tissue. Therefore, the present meta-analysis investigated MBL in diabetic patients and healthy individuals to evaluate bone tissue healing. MBL is an effective indicator of peri-implant bone integration and bone healing and one of the key metrics for assessing long-term implant success (55,56). Diabetic patients exhibited slightly higher MBL compared with healthy individuals. This may be attributed to abnormal bone metabolism and heightened inflammatory responses induced by the hyperglycemic states in diabetic patients. Alsahhaf *et al* (57) observed that,

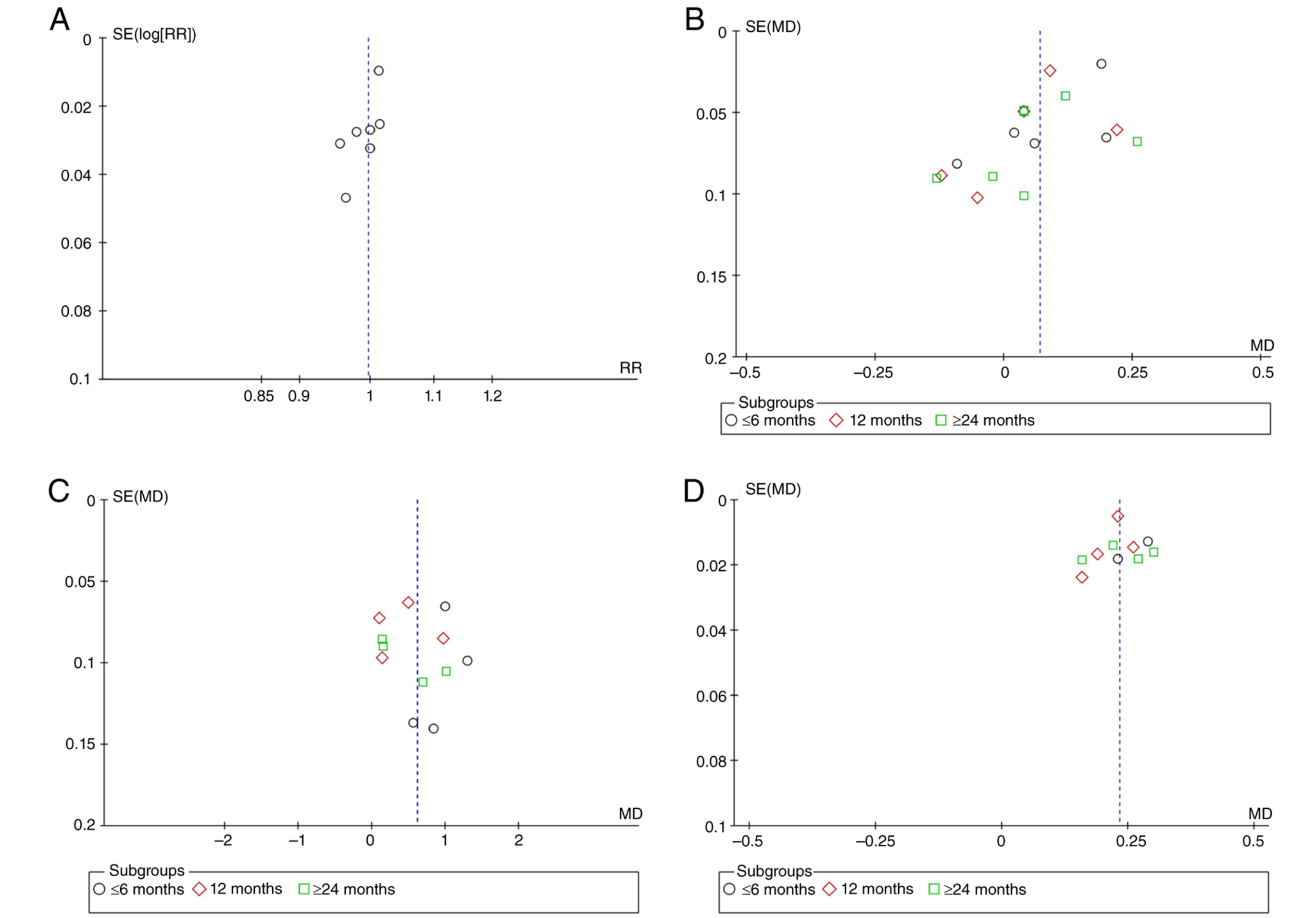

Figure 6. Peri-implant outcomes in diabetic patients compared with healthy individuals. (A) survival rate; (B) marginal bone loss; (C) probing depth; (D) bleeding on probing. SE, standard error; MD, mean difference.

compared with well-controlled diabetic patients and healthy individuals, poorly controlled diabetic patients experience markedly greater bone loss around the implants. The hyperglycemic environment promotes oxidative stress and the accumulation of advanced glycation end-products, which inhibit osteoblast activity and stimulate osteoclast formation, leading to increased bone resorption (8). Moreover, diabetic patients typically have microvascular complications, which may impair blood supply and healing capacity of peri-implant bone tissue (39). However, in the present study, the actual bone loss in well-controlled diabetic patients was relatively small (0.07 mm); in clinical practice, bone loss of 0.07 mm is almost negligible (55). The actual bone loss in patients with poorly controlled diabetes was 0.39 mm, which remains within an acceptable range (bone loss <0.2 mm/year is considered normal) (56). Therefore, such levels of bone loss are unlikely to have a notable impact on the long-term survival of implants. As previously noted, the similarity in implant SR between diabetic patients and healthy individuals further indicated that bone damage in diabetic patients does not affect implant survival. Therefore, diabetic patients can undergo IIP.

BOP and PD are key clinical indicators for assessing the health of peri-implant soft tissue. The present study found no significant difference in PD between well-controlled diabetic patients and healthy individuals, while BOP was markedly higher in diabetic patients. PD and BOP were markedly increased in patients with poor blood glucose control, suggesting more pronounced inflammation around the peri-implant tissue in diabetic individuals. For example, Gómez-Moreno *et al* (37) showed that poorly controlled diabetic patients (HbA1c ≥10.0%) have a significant increase in BOP during a 3-year follow-up after implant placement. Additionally, Lv *et al* (58) found that as HbA1c levels increased, the levels of bone metabolism negative regulators such as IL-6, TNF-α and RANKL also markedly increased, accompanied by a notable increase in PD around the implant. Hyperglycemia may decrease the resistance of periodontal tissues to bacterial infections, leading to microvascular changes in the gums and increased release of inflammatory mediators, thus exacerbating the inflammatory response in peri-implant tissues (59,60). Furthermore, impaired immune function in diabetic patients intensifies the inflammation around the implant (61). In the present study, PD for poorly controlled diabetic patients was 0.62 mm higher than in healthy patients. In clinical practice, a 0.62 mm increase in PD typically indicates mild inflammation, which usually does not have a notable impact on implant stability or success rates (62). While the differences in BOP were significant, the actual values were relatively small (0.12 and 0.23). It is typically considered that BOP <10% is indicative of healthy peri-implant tissue (63). Therefore, although diabetes increased the risk of inflammation in peri-implant soft tissues, effective glycemic control prevented severe inflammatory infections.

The included studies exhibited significant heterogeneity. Numerous factors may contribute to this variability. Firstly, the cohort studies may have been influenced by confounders, such as differences in implant types. Certain studies utilized Straumann Bone Level implants (Straumann AG), Brånemark System® MKIV (Nobel Biocare AB), or NobelSpeedy Groovy® (Nobel Biocare AB, Göteborg, Sweden) (37-40,44), which may impact the outcomes. Additionally, patients had varying HbA1c levels, and in certain cases, HbA1c levels decreased during follow-up (38). The follow-up duration also differed: Certain studies had follow-up periods <6 months (45), while others had follow-up durations of 24 or 36 months (37,43). The type of implants also varied, including single teeth, full-arch and all-on-four approaches. Furthermore, there were differences in the imaging methods used to measure MBL, such as intra-oral x-rays (38,39,43) and panoramic radiograph (41) or cone beam CT (46), which may lead to discrepancies in precision and consistency. Despite these differences, the main results remained consistent in subgroup and sensitivity analyses, indicating the robustness of the findings. Moreover, the use of a random-effects model mitigated the impact of heterogeneity on the results. Nevertheless, the presence of heterogeneity suggests that caution should be exercised when interpreting the findings, especially when extrapolating to a broader population. Future research should investigate the sources of heterogeneity and decrease its impact through standardized study designs and measurement techniques.

The present meta-analysis has several limitations. Firstly, certain studies included had small sample sizes, particularly the group of patients with poorly controlled diabetes (44,45). Small sample sizes may lead to insufficient statistical power, potentially failing to detect underlying differences and affecting the stability of the results. Secondly, due to the limited number of studies available for funnel plot analysis in some outcome measures, statistical tests such as Egger's test were not performed, as they would have low power and potentially yield misleading results (64). Therefore, publication bias was assessed qualitatively based on visual inspection of funnel plot symmetry. Future studies with larger sample sizes are needed to validate the robustness of our findings. Thirdly, while the studies categorized diabetic patients into well- and poorly controlled groups, there was a lack of detailed analysis of HbA1c levels. The precise level of blood glucose control may have a notable impact on implant success rates and the health of surrounding tissue, but the included studies did not fully explore this aspect. Furthermore, although the present study examined indicators such as MBL, PD and BOP, it lacked a detailed assessment of peri-implantitis, which is one of the primary causes of implant failure (53). Future research should investigate the incidence and risk factors of peri-implantitis in diabetic patients. Finally, the type of implants and surgical techniques varied, which could affect the comparability of the results. Future studies should aim to standardize implant types and surgical techniques to decrease the influence of confounding factors.

The present meta-analysis indicated that diabetic patients with good blood glucose control showed no significant difference in implant SR compared with healthy individuals, suggesting that IIP is feasible in diabetic patients. However, diabetic patients, especially those with poor blood glucose control, exhibit significant differences in MBL, PD and BOP, indicating that they may face a higher risk of peri-implant inflammation and tissue destruction following implant placement. Clinicians should pay particular attention to preoperative blood glucose control and postoperative peri-implant maintenance in diabetic patients. Regular monitoring of MBL, PD and BOP around the implant, along with personalized oral hygiene instructions and periodontal maintenance plans, may decrease the risk of peri-implantitis and improve the long-term SR of implants.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

ZL, HY and XZ conceived the study. HL and XZ analyzed the data. ZL and HY confirm the authenticity of all the raw data. ZL and HY wrote the manuscript. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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