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REVIEW ARTICLE

ORGANIZATIONAL AND CLINICAL PRINCIPLES OF SURGICAL DENTAL CARE IN PATIENTS WITH TYPE 2 DIABETES MELLITUS: A SCOPING REVIEW

Hakob Khachatryan[1]

[1]Department of Surgical Stomatology and Maxillofacial Surgery, Yerevan State Medical University after Heratsi, Yerevan, Armenia

***Corresponding authors:** Hakob Khachatryan, Department of Surgical Stomatology and Maxillofacial Surgery, Yerevan State Medical University after M. Heratsi, Yerevan, Armenia e-mail- hakobsurgeon@gmail.com

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ABSTRACT

Background: The aim of this scoping review was to map the current evidence regarding the organization and provision of surgical dental care for patients with type 2 diabetes mellitus, with particular emphasis on oral manifestations, wound healing, dental implant therapy, peri-implant diseases, and preventive management strategies.

Methods: A comprehensive literature search was conducted in MEDLINE, Scopus, Web of Science, PubMed, and Google Scholar. The review included studies addressing the organization of dental care in patients with type 2 diabetes mellitus, the relationship between glycemic control and oral complications, oral manifestations of diabetes, wound healing following dental procedures, implant therapy, osseointegration, and peri-implant diseases. A total of 132 publications were identified. Following title and abstract screening and full-text assessment according to predefined eligibility criteria, 64 articles were included in the final scoping review. The evidence was mapped and synthesized thematically according to the main clinical areas of surgical dental care.

Results: The reviewed literature demonstrated that patients with type 2 diabetes mellitus may present with a broad spectrum of oral complications, including periodontal disease, xerostomia and salivary dysfunction, taste disturbances, oral infections, impaired wound healing, tooth loss, and postoperative complications such as alveolar osteitis. Hyperglycemia was associated with impaired wound healing, altered bone metabolism, compromised osseointegration, and an increased susceptibility to peri-implant inflammatory complications. The evidence also highlighted the importance of glycemic control, periodontal and oral hygiene status, appropriate patient selection, preventive protocols, implant surface modification, vitamin D status, and long-term maintenance in the management of diabetic patients undergoing surgical dental treatment.

Conclusion: This scoping review demonstrates that surgical dental care in patients with type 2 diabetes mellitus requires individualized treatment planning, adequate metabolic control, comprehensive preventive strategies, and long-term clinical monitoring. Although diabetes mellitus may increase the risk of postoperative and peri-implant complications, current evidence indicates that dental surgical and implant treatment can be successfully performed in appropriately selected and adequately controlled patients. Further well-designed clinical studies are needed to clarify optimal protocols for surgical dental management and implant therapy in this population.

Keywords: Type 2 diabetes mellitus; surgical dental care; glycemic control; oral manifestations; wound healing; dental implants; peri-implantitis; osseointegration; preventive dental management; scoping review

INTRODUCTION

Diabetes mellitus is a chronic metabolic disorder characterized by impaired glucose regulation and disturbances in carbohydrate, lipid, and protein metabolism. It remains a major global health problem and is associated with substantial medical and social consequences.[1–3] The worldwide prevalence of diabetes has increased considerably over recent decades, and current estimates indicate that hundreds of millions of people are living with the disease.[4–6]

Persistent hyperglycemia contributes to the development of both microvascular and macrovascular complications and is also associated with impaired immune function, delayed tissue repair, vascular dysfunction, and alterations in bone metabolism.[7–11]

The effects of diabetes extend beyond the major systemic complications of the disease and involve a wide range of oral tissues and functions. Chronic hyperglycemia can impair vascularization, alter inflammatory and immune

responses, reduce fibroblast activity and collagen synthesis, and interfere with normal tissue repair. These changes may increase susceptibility to infection and contribute to poorer healing following dental and oral surgical procedures.[7–11]

A broad spectrum of oral manifestations has been reported in patients with diabetes mellitus, including periodontal disease, xerostomia, salivary gland dysfunction, oral fungal infections, taste disturbances, delayed wound healing, and tooth loss.[12–14] Periodontal disease is particularly important because it represents one of the most common chronic inflammatory conditions affecting patients with diabetes.[15,16] The relationship between diabetes and periodontal disease is bidirectional: poor glycemic control may promote periodontal tissue destruction, while persistent periodontal inflammation may adversely affect metabolic control.[17,18]

The biological mechanisms underlying this relationship involve dysregulated inflammatory and immune responses. Hyperglycemia and the accumulation of advanced glycation-related products can contribute to an exaggerated inflammatory response, with increased production of mediators such as tumor necrosis factor alpha, interleukin-1 beta, and prostaglandin E2. These mediators can stimulate osteoclastic activity and promote destruction of periodontal supporting tissues.[19] Consequently, patients with diabetes may have an increased need for surgical dental interventions, including tooth extraction, periodontal procedures, and implant-supported rehabilitation.

Tooth extraction presents particular challenges in patients with diabetes because normal socket healing depends on adequate vascularization, inflammatory regulation, fibroblast activity, collagen formation, and bone remodeling. Diabetes-related microvascular changes and impaired tissue repair may delay epithelialization and connective tissue regeneration and may increase susceptibility to postoperative infection.[20–23] These problems are especially relevant during the early postoperative period, when stable clot formation, vascularization, and tissue repair are essential for uncomplicated healing.

Alveolar osteitis is an important postoperative complication following tooth extraction and may be particularly problematic in patients with impaired healing capacity. Delayed socket healing, altered angiogenesis, impaired host defense, and increased bacterial colonization may contribute to its development in patients with diabetes.[20–23] Clinically, alveolar osteitis can cause considerable postoperative pain and delayed recovery and may negatively affect oral function and quality of life. Appropriate preventive and therapeutic approaches are therefore an important component of surgical dental care in patients with diabetes.[24]

Diabetes-related impairment of wound healing is not limited to soft tissues. Hyperglycemia can also interfere with osteoblastic differentiation, bone formation, and normal bone remodeling.[7,8] These alterations are particularly relevant when surgical procedures involve bone healing, such as tooth extraction and dental implant placement. Because progressive periodontal disease and tooth loss may lead to functional impairment and reduced oral rehabilitation options, prosthetic treatment is frequently required. Conventional removable prostheses may be limited by alveolar bone resorption and reduced prosthetic stability.[25] Dental implants therefore represent an important treatment option for restoring mastication, oral function, and quality of life in appropriately selected patients with diabetes mellitus.[26]

The use of dental implants in patients with diabetes has increased, and available evidence indicates that implant therapy can provide satisfactory clinical outcomes when patients are appropriately selected and metabolic control is adequately managed.[26–29] Nevertheless, diabetes remains an important biological risk factor that may influence osseointegration and implant survival.[30,31] Persistent hyperglycemia may suppress osteoblastic activity, increase osteoclastic bone resorption, alter calcium and phosphorus metabolism, impair collagen formation, and interfere with normal bone remodeling. These changes may reduce bone-implant contact and delay the establishment of stable osseointegration.

Peri-implant disease represents another important concern in diabetic patients receiving implant therapy. Evidence from systematic reviews and observational studies suggests that diabetes, particularly when poorly controlled, may be associated with an increased risk of peri-implant inflammation and marginal bone loss.[32–36] The biological basis of this association includes chronic inflammation, altered immune defense, oxidative stress, impaired tissue repair, and disturbances in bone remodeling.[32–36] At the same time, the magnitude of the association varies among studies, indicating that diabetes should not be considered an absolute contraindication to implant treatment. Glycemic control, oral hygiene, periodontal status, smoking, and other patient-related factors may substantially influence clinical outcomes.

The management of implant patients with diabetes has therefore shifted from considering diabetes itself as a contraindication toward identifying and controlling modifiable risk factors. Appropriate patient selection, optimization of glycemic control, periodontal treatment, maintenance of oral hygiene, careful surgical planning,

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and regular supportive follow-up are important components of successful implant therapy.[26,29,32–36]

In addition to patient-related factors, implant surface characteristics may influence the biological response to implantation. Modern surface modification techniques, including sandblasted large-grit acid-etched surfaces, hydroxyapatite and calcium-phosphate coatings, anodic oxidation, and other surface treatments, have been developed to improve early bone response and osseointegration.[37–39] These approaches may be particularly relevant in patients with compromised bone-healing capacity.

Ultraviolet photofunctionalization is one of the surface modification approaches that has received increasing attention. Ultraviolet treatment can alter the physicochemical properties of titanium surfaces, increasing surface hydrophilicity and improving the interaction between the implant surface and biological tissues. Experimental and clinical studies have reported enhanced osteoblast attachment and improved early osseointegration following photofunctionalization, together with potential reductions in bacterial adhesion.[40–44] Such approaches may have particular relevance for patients with diabetes, although further clinical evidence is required to determine their long-term benefits in this population.

Diabetes also affects skeletal metabolism and bone quality. Alterations in bone formation and remodeling have been described in patients with diabetes mellitus and may influence the biological environment surrounding dental implants.[45–48] Biochemical markers of bone turnover, including osteocalcin and beta-CrossLaps, have attracted interest as potential indicators of bone metabolic activity. Recent clinical research involving patients with type 2 diabetes and dental implants suggests that assessment of bone metabolism markers may provide additional information regarding the biological processes associated with implant therapy.[49]

Vitamin D represents another potentially relevant factor in the management of diabetic patients undergoing implant treatment. Vitamin D participates in calcium and phosphate homeostasis, bone mineralization, immune regulation, and bone remodeling. Several studies have investigated the relationship between vitamin D status and implant osseointegration and have suggested that vitamin D deficiency may be associated with impaired bone healing and an increased risk of early implant complications.[50–53] Clinical investigations have also explored whether correction of vitamin D deficiency before implant placement may improve the biological conditions required for osseointegration.[54–57] Although the available evidence remains heterogeneous, assessment of vitamin D status may be considered as part of a broader evaluation of patients with diabetes who are planned for implant therapy.

The provision of surgical dental care to patients with type 2 diabetes therefore requires an integrated approach that considers both oral and systemic factors. Assessment of glycemic control, medical history, medication use, periodontal status, oral hygiene, smoking status, and potential metabolic risk factors should form part of treatment planning.[58–63] Close communication between dental professionals and the physicians responsible for the patient's diabetes management may facilitate safer surgical care and reduce the risk of postoperative complications. Long-term professional maintenance is also particularly important for patients receiving implant-supported prostheses.[64]

Taken together, the available literature demonstrates that diabetes mellitus can influence several interconnected aspects of surgical dental care, from periodontal inflammation and extraction-socket healing to bone metabolism, osseointegration, peri-implant disease, and long-term implant maintenance. However, the evidence is distributed across different clinical and biological fields, and the factors influencing treatment outcomes are not uniformly characterized. A comprehensive mapping of the available evidence is therefore warranted.

The aim of this scoping review was to map and synthesize the available evidence regarding the organizational and methodological principles of providing surgical dental care to patients with type 2 diabetes mellitus, with particular emphasis on oral manifestations, wound healing and alveolar osteitis after tooth extraction, dental implant therapy and osseointegration, peri-implant diseases, bone metabolism, vitamin D status, implant surface modification, and preventive and supportive management strategies.

2. METHODOLOGY

2.1 Search Strategy

A comprehensive literature search was conducted to identify published evidence concerning the organization and provision of surgical dental care for patients with type 2 diabetes mellitus. The search was performed in PubMed, MEDLINE, Scopus, Web of Science, and Google Scholar.

The search strategy was developed around the principal concepts addressed in this review, including diabetes mellitus, type 2 diabetes mellitus, oral manifestations, glycemic control, dental care, surgical dental care, wound healing, tooth extraction, alveolar osteitis, periodontal disease, dental implants, osseointegration, peri-

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implantitis, bone metabolism, vitamin D, and implant surface modification.

The following keywords and combinations of keywords were used:

- Diabetes mellitus
- Type 2 diabetes mellitus
- Oral manifestations
- Dental care
- Surgical dental care
- Tooth extraction
- Wound healing
- Alveolar osteitis
- Periodontal disease
- Dental implants
- Dental implantation
- Osseointegration
- Peri-implantitis
- Bone metabolism
- Vitamin D
- Glycemic control

The search terms were combined using Boolean operators (AND and OR), where appropriate, to identify studies addressing the principal clinical and biological aspects of surgical dental care in patients with type 2 diabetes mellitus.

Additional relevant studies were identified by manually reviewing the reference lists of eligible publications and relevant systematic and narrative review articles. Reference-list screening was performed to identify potentially relevant publications that may not have been retrieved through the electronic database searches.

The search process was designed to identify evidence concerning both clinical outcomes and the organizational principles of surgical dental management, including preoperative assessment, glycemic control, periodontal management, postoperative wound care, implant therapy, peri-implant disease prevention, and long-term supportive maintenance.

2.2 Eligibility Criteria and Study Selection

Studies were considered eligible when they investigated one or more aspects of dental or surgical dental care in patients with diabetes mellitus, with particular emphasis on type 2 diabetes mellitus. The review included human studies addressing oral manifestations of diabetes, periodontal disease, wound healing following dental procedures, tooth extraction and alveolar osteitis, dental implant therapy, osseointegration, peri-implant diseases, bone metabolism, vitamin D status, implant surface modification, or preventive and supportive dental management.

The review considered randomized controlled trials, clinical trials, cohort studies, case-control studies, cross-sectional studies, observational studies, and relevant systematic or narrative reviews when they provided information directly relevant to the objectives of the review.

Studies were excluded when they were unrelated to dental care in patients with diabetes mellitus, were conducted exclusively in animals or in vitro, or were conference abstracts, letters to the editor, book chapters, or duplicate publications. Case reports were also excluded from the main evidence synthesis.

The titles and abstracts of the identified publications were independently screened by two reviewers. Potentially relevant articles were subsequently assessed in full text against the predefined eligibility criteria. Disagreements regarding study eligibility were resolved through discussion and consensus.

The study selection process was documented according to the principles of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR).

The numbers of identified, screened, assessed, excluded, and included publications are presented in the PRISMA-ScR flow diagram (Figure 1).

2.3 Data Charting and Extraction

Data from the included publications were independently extracted by two reviewers using a standardized data extraction form.

The information collected included:

- first author and year of publication;
- study design;
- study population;
- sample characteristics;
- diabetes-related characteristics;
- duration and/or control of diabetes where reported;
- dental intervention or clinical condition investigated;
- principal clinical outcomes;
- biological or biochemical outcomes;
- implant-related outcomes where applicable; and
- major findings relevant to surgical dental care.

Particular attention was given to evidence concerning oral manifestations, periodontal disease, postoperative wound healing, alveolar osteitis, dental implant survival, osseointegration, peri-implantitis, bone metabolism, vitamin D status, implant surface modification, and preventive management.

Where relevant, information regarding glycemic control, HbA1c levels, duration of diabetes, periodontal status, oral hygiene, smoking, and other patient-related factors potentially influencing dental treatment outcomes was also recorded.

For implant-related studies, information concerning implant survival, implant failure, marginal bone loss,

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peri-implant inflammation, osseointegration, implant surface characteristics, and other relevant clinical or radiographic outcomes was extracted.

For studies addressing bone metabolism and vitamin D, information concerning biochemical markers, vitamin D status, supplementation, bone turnover, osseointegration, and implant-related outcomes was recorded where available.

2.4 Evidence Characterization

As this study was designed as a scoping review, the included evidence was characterized according to study design, clinical topic, patient population, intervention or exposure, and principal outcomes.

The purpose of this process was to identify and map the breadth and characteristics of the available evidence rather than to calculate a pooled effect estimate or perform a quantitative meta-analysis.

The evidence was organized into the following major thematic areas:

- Oral manifestations of diabetes mellitus;
- Periodontal disease and inflammatory complications;
- Wound healing and complications following tooth extraction;
- Alveolar osteitis;
- Dental implant therapy and osseointegration;
- Peri-implantitis and peri-implant diseases;
- Bone metabolism and biochemical markers;
- Vitamin D and implant-related outcomes;
- Implant surface modification; and
- Preventive and supportive dental management.

The thematic organization was used to facilitate synthesis of the available evidence and to identify areas in which diabetes mellitus may influence surgical dental outcomes.

Because the primary objective of a scoping review is to map the available evidence rather than to estimate a pooled treatment effect, no meta-analysis was performed.

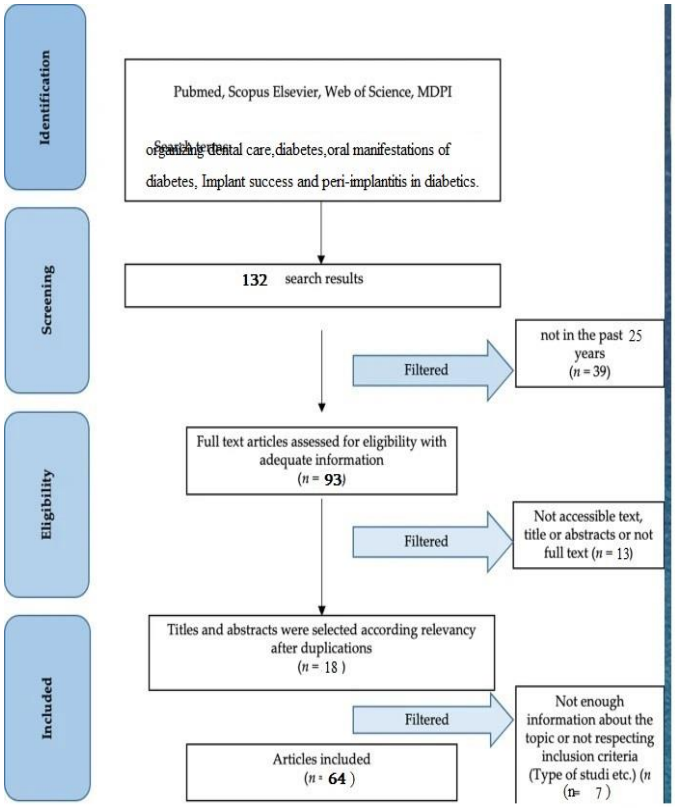
2.5 Data Synthesis

The findings of the included studies were synthesized narratively and organized according to the major clinical and methodological themes identified during the review process.

The synthesis focused on the relationship between diabetes mellitus and oral health, the effects of glycemic control on surgical dental outcomes, postoperative wound healing, tooth extraction and alveolar osteitis, implant therapy and osseointegration, peri-implant diseases, bone metabolism, vitamin D status, implant surface modification, and preventive and supportive management.

The evidence was compared qualitatively across the different study designs and clinical populations, with particular attention to consistent findings, areas of heterogeneity, and clinically relevant factors that may modify treatment outcomes.

The review process and reporting were guided by the principles of the PRISMA-ScR framework for scoping reviews. The study selection process is presented in the PRISMA-ScR flow diagram (Figure 1).



3.2 Oral Manifestations of Diabetes Mellitus

A total of 132 publications were identified, and 64 articles were included in the final evidence synthesis after application of the predefined eligibility criteria.

No quantitative pooling of effect estimates was performed because of the heterogeneity of study designs, populations, interventions, clinical outcomes, and definitions of glycemic control and implant-related outcomes.

3. RESULTS

3.1 Search Results

A total of 132 publications were identified through the electronic database search and additional identification procedures. Following removal of duplicate records and screening of titles and abstracts, potentially relevant publications were assessed for eligibility in full text.

After application of the predefined inclusion and exclusion criteria, 64 articles were included in the final evidence synthesis.

The included publications covered a broad range of clinical and biological aspects of surgical dental care in patients with diabetes mellitus, including oral

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manifestations, periodontal disease, postoperative wound healing, tooth extraction and alveolar osteitis, dental implant therapy, osseointegration, peri-implant diseases, bone metabolism, vitamin D, implant surface modification, and preventive and supportive management.

The overall study identification, screening, eligibility assessment, and inclusion process is presented according to the PRISMA-ScR framework in Figure 1.

3.2 Oral Manifestations of Diabetes Mellitus

The reviewed literature demonstrated that patients with diabetes mellitus may experience a broad range of oral manifestations and complications. These include periodontal disease, dental caries, salivary gland dysfunction, xerostomia, taste disturbances, fungal and bacterial infections, delayed wound healing, and tooth loss. The main oral manifestations identified in patients with type 2 diabetes mellitus and their relevance to surgical dental care are presented in Figure 2 and summarized in Table 1.

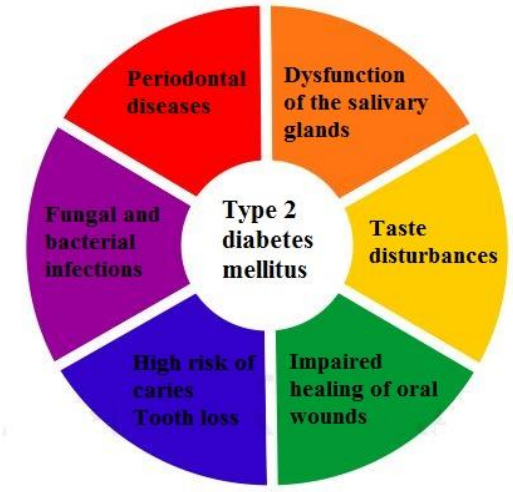

Figure 2. Oral manifestations in patients with diabetes mellitus

Table 1. Oral manifestations of type 2 diabetes mellitus

Oral manifestation	Main characteristics	Surgical dental relevance
Periodontal disease	Chronic inflammatory periodontal destruction	Increased risk of periodontal and peri-implant complications
Xerostomia	Reduced salivary flow	Increased caries and infection risk
Delayed wound healing	Impaired tissue repair	Important after extraction and oral surgical procedures
Candida infection	Increased susceptibility to fungal infection	Requires appropriate infection prevention and management
Tooth loss	Frequently associated with periodontal disease and other oral complications	May require implant-supported or other prosthetic rehabilitation

Periodontal disease was consistently identified as one of the most important oral complications associated with diabetes mellitus. Patients with diabetes may experience more pronounced periodontal tissue destruction because of impaired neutrophil function, persistent low-grade inflammation, vascular alterations, and dysregulation of the host immune response.

These mechanisms may reduce the ability of periodontal tissues to respond adequately to bacterial challenge and may contribute to more severe and progressive periodontal damage. Patients with diabetes mellitus and periodontitis have been reported to exhibit increased levels of inflammatory mediators, including tumor necrosis factor alpha (TNF-α), interleukin-1 beta (IL-1β), and prostaglandin E2. Increased inflammatory activity promotes osteoclast activation and contributes to progressive destruction of periodontal supporting tissues. At the same time, chronic periodontal inflammation may adversely affect glycemic control, creating a bidirectional relationship in which diabetes increases the severity of periodontal disease while periodontal inflammation may further complicate metabolic control.

The reviewed evidence therefore supports the consideration of periodontal treatment in diabetic patients not simply as a local dental intervention but as an important component of comprehensive disease management. Appropriate periodontal therapy, effective oral hygiene, regular professional maintenance, and continued periodontal monitoring may help reduce oral inflammatory burden and support better overall health outcomes.

3.3 Wound Healing Disturbances

The literature demonstrated that persistent hyperglycemia adversely affects several stages of the normal wound-healing process. Diabetes-related alterations in angiogenesis, collagen synthesis, fibroblast proliferation, immune function, and extracellular matrix remodeling can delay the repair of oral soft tissues and impair bone regeneration. Reduced vascularization, compromised local blood flow, altered growth-factor activity, and increased apoptosis of gingival fibroblasts collectively contribute to delayed connective tissue repair and prolonged postoperative recovery. Following

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dental surgical procedures, these abnormalities may result in delayed epithelialization, increased susceptibility to infection, and impaired healing of both soft and hard tissues. The extraction socket is particularly vulnerable because successful healing requires an adequate inflammatory response, formation and stabilization of a blood clot, angiogenesis, granulation tissue formation, and subsequent bone remodeling. Disturbances in these processes may increase the likelihood of postoperative complications in patients with diabetes mellitus.

Alveolar osteitis is among the clinically important postoperative complications reported after tooth extraction in diabetic patients. Delayed healing of the extraction socket, impaired angiogenesis, altered immune defense, and increased bacterial colonization may contribute to its development. The condition may cause substantial postoperative pain and delay normal socket healing, thereby increasing the need for additional local treatment and follow-up. Various local therapeutic approaches have been investigated to improve postoperative healing in diabetic patients. These include antiseptic protocols, specialized wound dressings, regenerative approaches, and laser-based treatment modalities.
The principal mechanisms by which type 2 diabetes mellitus may impair oral wound healing, including impaired angiogenesis, altered immune responses, reduced fibroblast activity, and disturbed tissue repair, are illustrated in Figure 3.

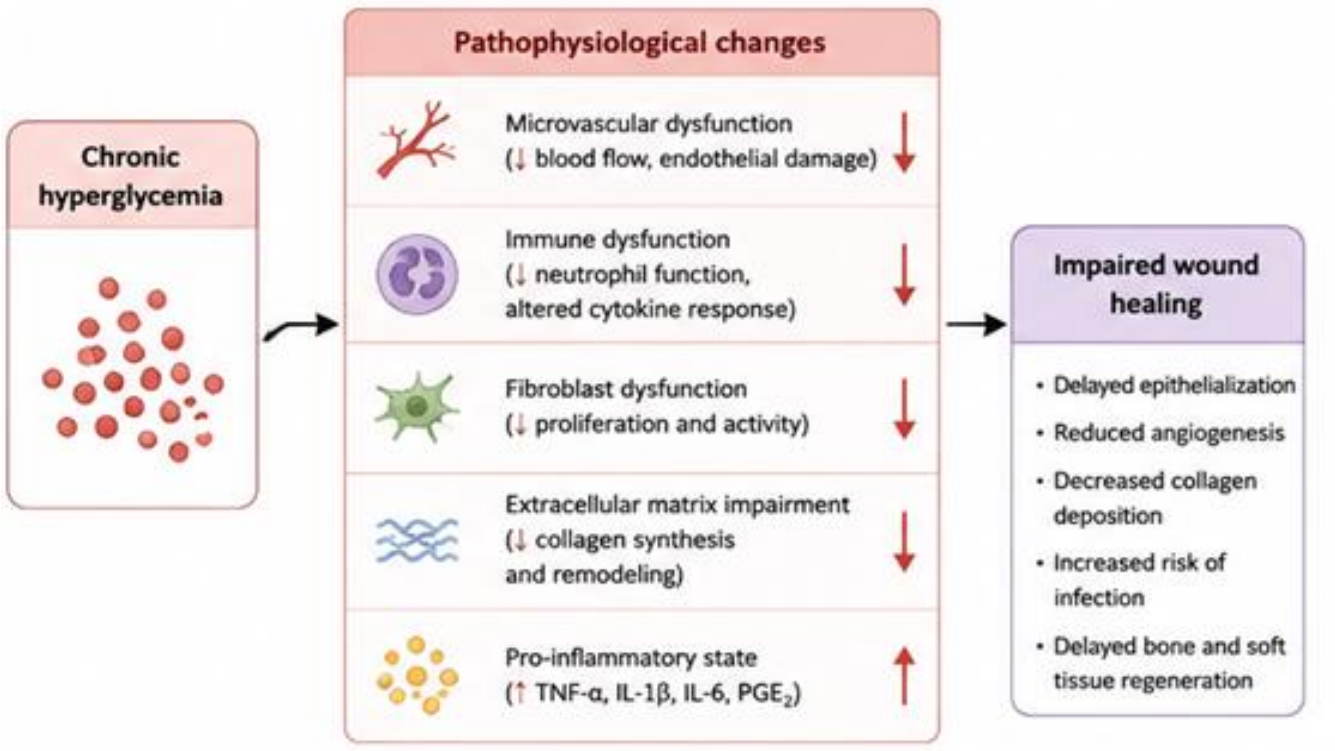

Figure 3. Mechanisms of impaired wound healing in patients with type 2 diabetes mellitus.

3.4 Dental Implant Osseointegration in Patients with Type 2 Diabetes Mellitus

Tooth loss in patients with diabetes mellitus may adversely affect nutrition, mastication, speech, and overall quality of life. Dental implantation provides an important option for prosthetic rehabilitation and functional restoration. However, the biological environment associated with prolonged hyperglycemia may negatively influence bone healing, osseointegration, implant stability, and long-term implant survival.
Persistent hyperglycemia may suppress osteoblastic activity while increasing osteoclastic activity, alter calcium and phosphorus metabolism, reduce collagen synthesis, and interfere with normal bone remodeling. These effects are accompanied by diabetes-related molecular and cellular changes, including increased oxidative stress, elevated production of pro-inflammatory cytokines, endothelial dysfunction, and accumulation of advanced glycation end products (AGEs).
The combined effects of these mechanisms may compromise the biological response of bone tissue to the implant surface. The interaction between hyperglycemia, inflammation, impaired bone metabolism, and implant healing is illustrated in Figure 4.

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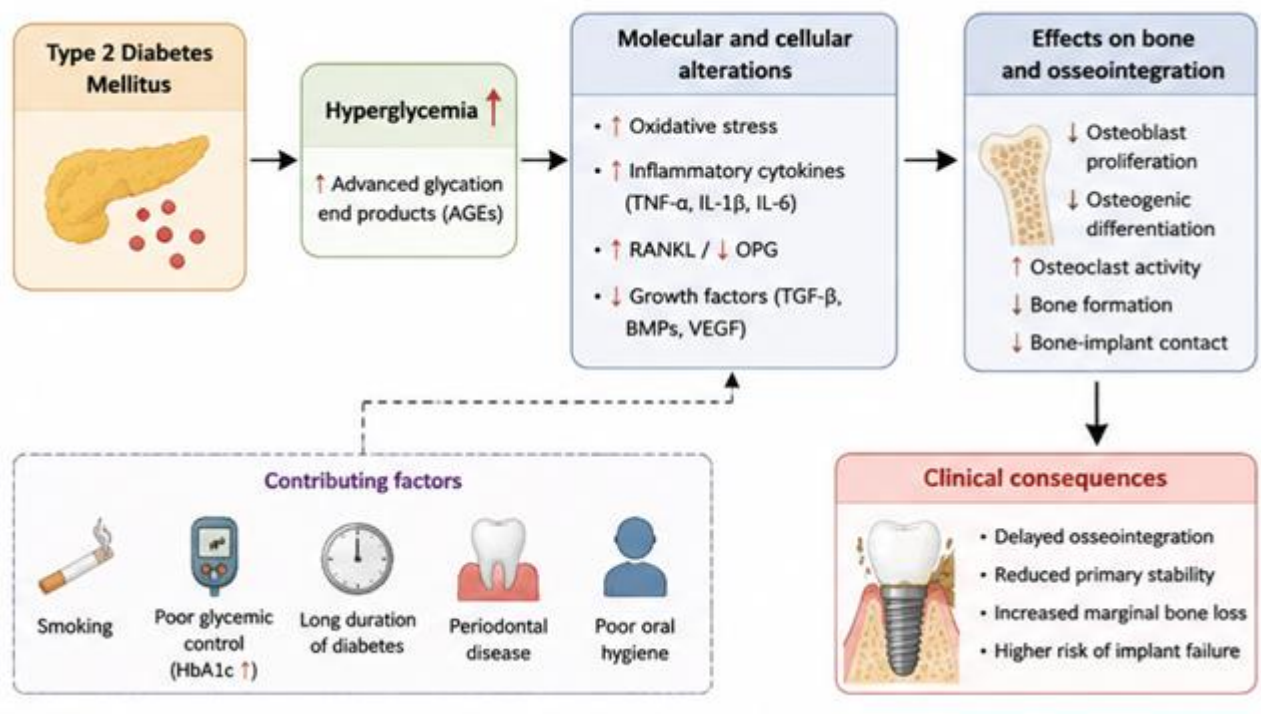

Figure 4. Effects of type 2 diabetes mellitus on osseointegration and implant success.

These changes may reduce bone-implant contact, delay the early stages of osseointegration, compromise implant stability, and increase the likelihood of implant failure in susceptible patients.

Several studies have demonstrated that optimization of implant surface characteristics may improve the biological response to implants in diabetic patients.

Surface modification techniques such as plasma-sprayed titanium coatings, hydroxyapatite deposition, calcium phosphate coatings, sandblasted large-grit acid-etched (SLA) surfaces, and anodic oxidation have been investigated as approaches to enhance bone integration. These technologies are designed to modify surface roughness, chemical composition, surface energy, and biological interactions at the bone-implant interface. Among more recent approaches, ultraviolet (UV) photofunctionalization has attracted particular interest. UV treatment modifies the physicochemical characteristics of titanium surfaces and converts relatively hydrophobic implant surfaces into highly hydrophilic or superhydrophilic surfaces.

This modification may improve protein adsorption, osteoblast attachment, cellular activity, and early bone formation around the implant. In addition to its effects on cellular attachment and osseointegration, UV photofunctionalization may reduce bacterial adhesion to titanium surfaces. This property may be particularly relevant in patients with diabetes mellitus because impaired immune responses and altered tissue healing can increase susceptibility to peri-implant infection.

Thus, optimization of implant surface characteristics represents a potentially useful component of implant treatment in appropriately selected diabetic patients.

3.5 Peri-implantitis and Diabetes Mellitus

The relationship between diabetes mellitus and peri-implantitis has been examined in numerous clinical studies and systematic reviews.

Although the magnitude of the association varies among studies, the available evidence generally suggests that diabetes mellitus, particularly when glycemic control is inadequate, may increase susceptibility to peri-implant inflammatory complications.

Persistent hyperglycemia may contribute to chronic systemic and local inflammation, impaired immune function, increased oxidative stress, vascular dysfunction, and alterations in bone metabolism. These changes can affect peri-implant tissue homeostasis and may interfere with the ability of the tissues to control bacterial biofilm. In the presence of dental biofilm, an altered inflammatory response may promote soft-tissue inflammation, progressive marginal bone loss, and impaired bone remodeling around the implant.

The principal mechanisms underlying the development of peri-implantitis in patients with type 2 diabetes mellitus are illustrated in Figure 5.

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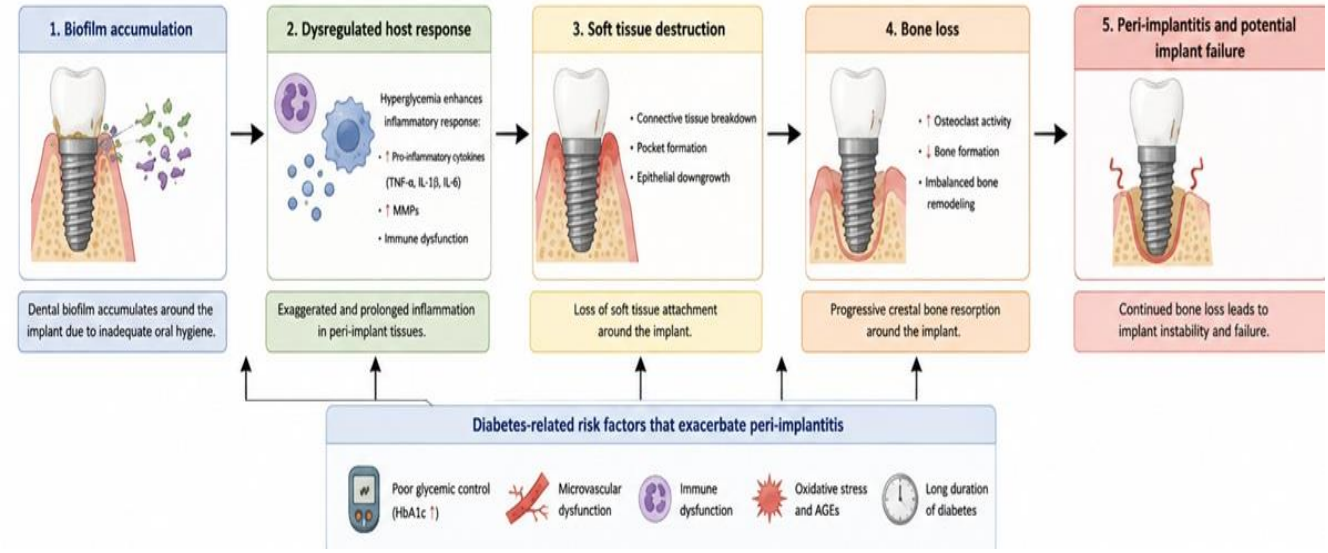

Figure 5. Pathogenesis of peri-implantitis in patients with type 2 diabetes mellitus.

A systematic review and meta-analysis reported an increased risk of peri-implantitis among patients with diabetes mellitus compared with non-diabetic individuals, whereas a significant association between diabetes and peri-implant mucositis was not consistently demonstrated [34].

These findings suggest that the influence of diabetes may become particularly evident once inflammatory disease progresses from the peri-implant mucosa to the supporting peri-implant tissues.

Poor glycemic control appears to be an important factor in this process. Elevated HbA1c levels have been associated with less favorable peri-implant clinical and radiographic findings, including increased probing depth, bleeding on probing, and crestal bone loss [32,34].

These observations support the importance of metabolic control as part of the long-term management of diabetic patients receiving implant therapy.

Several patient-related and clinical characteristics may influence implant outcomes in patients with diabetes mellitus. These include glycemic control, smoking, periodontal status, oral hygiene, and general metabolic control.

The influence of diabetes duration is less clear, and the available evidence does not establish disease duration as an independent predictor of implant failure [26].

The principal clinical and disease-related factors potentially affecting implant outcomes in patients with diabetes mellitus are summarized in Table 2.

Table 2. Risk factors and clinical characteristics influencing implant outcomes in patients with diabetes mellitus.

Risk factor / clinical characteristic	Evidence-based effect on implant outcomes	Reference(s)
Poor glycemic control (elevated HbA1c)	Associated with poorer peri-implant clinical and radiographic parameters, including increased probing depth, bleeding on probing, and crestal bone loss; may increase susceptibility to peri-implant inflammatory complications	[32,34]
Smoking	May adversely affect osseointegration and peri-implant tissue health and may increase the risk of implant complications	[34]
Diabetes mellitus / inadequate metabolic control	Diabetes mellitus is associated with a higher overall risk of implant failure and greater marginal bone loss in meta-analytic evidence, although outcomes may be more favorable when glycemic control is maintained	[26,29]
Long duration of diabetes	Current evidence is insufficient to	[26]

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	establish diabetes duration as an independent predictor of implant failure or peri-implant complications	
History of periodontal disease	May increase susceptibility to peri-implant inflammatory complications and peri-implantitis, particularly in patients with diabetes	[33,34,36]
Poor oral hygiene / inadequate plaque control	Promotes dental biofilm accumulation and may contribute to peri-implant mucosal inflammation and peri-implantitis	[34,36]
Peri-implant inflammatory disease	May lead to progressive marginal bone loss, impaired implant stability, and, in advanced cases, implant failure	[32,34,36]

Despite the increased susceptibility to peri-implant complications observed in some diabetic patients, diabetes mellitus should not be considered an absolute contraindication to dental implant therapy.

The available evidence indicates that implant treatment can be performed successfully when appropriate precautions are implemented, particularly when glycemic control is adequate and oral hygiene and periodontal health are maintained [26,29].

The systematic review by Wagner et al. reported that poorly controlled diabetes was associated with more frequent peri-implantitis and greater long-term implant loss, whereas patients with controlled diabetes demonstrated outcomes that were closer to those observed in individuals without diabetes [26].

These findings emphasize the importance of individualized patient selection, metabolic assessment, periodontal stabilization, appropriate surgical planning, and long-term supportive maintenance.

3.6 Bone Metabolism Markers and Vitamin D

Diabetes mellitus is associated with clinically relevant alterations in bone metabolism.

Chronic hyperglycemia may affect osteoblast and osteoclast activity, bone turnover, mineral metabolism, and the quality of the bone surrounding dental implants.

These alterations may be particularly important during the early stages of osseointegration, when active bone formation and remodeling are required to establish a stable bone-implant interface.

Biochemical markers of bone turnover, including osteocalcin and β-CrossLaps, have therefore attracted attention in the assessment of bone metabolism in patients with diabetes mellitus.

Reduced levels of osteocalcin and β-CrossLaps have been reported in diabetic patients and may be related to alterations in glucose metabolism. Assessment of these markers may provide additional information regarding bone metabolic activity and may potentially have prognostic value when evaluating osseointegration and implant outcomes [49].

Recent clinical evidence has also highlighted the possible relevance of bone metabolism markers in patients with type 2 diabetes mellitus receiving dental implants.

The relationship between systemic metabolic alterations, bone turnover, and implant healing suggests that biochemical assessment may complement conventional clinical and radiographic evaluation in selected patients.

Vitamin D is another factor of potential importance in this context.

Vitamin D plays a central role in calcium and phosphorus homeostasis, bone mineralization, osteoblast function, and regulation of inflammatory responses.

Vitamin D deficiency is frequently reported in patients with type 2 diabetes mellitus and may therefore represent an additional factor that could negatively influence bone healing and implant integration.

Several studies have investigated the relationship between vitamin D status and dental implant outcomes [50–57].

Experimental and clinical evidence suggests that adequate vitamin D availability may support bone formation and osseointegration, whereas severe deficiency may be associated with impaired bone healing and a potentially greater risk of early implant complications.

Vitamin D supplementation before implant placement has therefore been proposed as a possible strategy in patients with documented deficiency.

Some studies have reported improved bone formation and implant healing following correction of vitamin D deficiency, although the available evidence remains heterogeneous and does not support routine supplementation in all patients irrespective of their vitamin D status.

Consequently, assessment of vitamin D status and correction of clinically significant deficiency may be considered as part of individualized preoperative assessment, particularly in diabetic patients with additional risk factors for impaired bone healing.

3.7 Preventive Dental Management

The reviewed evidence indicates that successful surgical dental care in patients with type 2 diabetes mellitus

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requires an individualized and preventive approach.

Treatment planning should take into consideration the patient's degree of glycemic control, medical history, diabetes-related systemic complications, current medications, periodontal condition, oral hygiene, and previous history of postoperative complications.

Before surgical dental procedures, the clinician should assess the patient's metabolic status and determine whether additional medical consultation is necessary.

Particular attention should be given to patients with poorly controlled diabetes, significant systemic complications, active periodontal disease, or a history of impaired wound healing.

Preventive management should include regular dental examinations, professional oral hygiene procedures, appropriate periodontal maintenance, monitoring of glycemic control, reduction of treatment-related stress, and communication with the patient's physician when indicated. In patients undergoing implant therapy, prevention should continue after implant placement through regular clinical assessment, professional maintenance, monitoring of peri-implant tissues, and reinforcement of individualized oral hygiene measures. Long-term supportive care is particularly important because the risk of peri-implant inflammation does not end after successful osseointegration. Maintenance of adequate plaque control and metabolic stability may reduce the likelihood of peri-implant complications and support the long-term function of dental implants [26,29,32–36,64].

The principal elements of an individualized preventive and supportive management approach for surgical dental care in patients with type 2 diabetes mellitus are summarized in Figure 6.

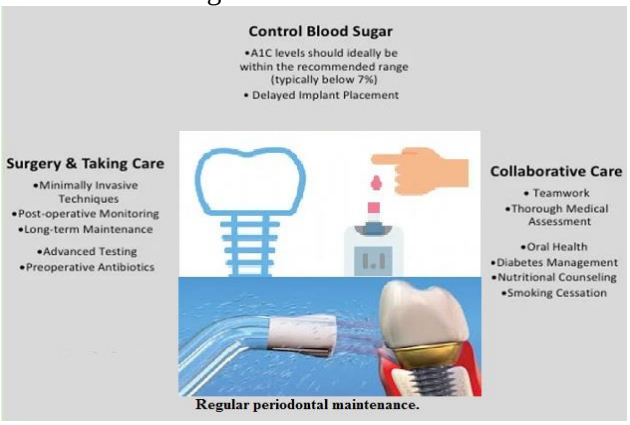

Figure 6. Integrated preventive and supportive management approach for surgical dental care in patients with type 2 diabetes mellitus.

4. DISCUSSION

This scoping review demonstrates that type 2 diabetes mellitus has a substantial influence on the oral environment and on the outcomes of surgical dental treatment. The available literature indicates that persistent hyperglycemia affects several biological processes that are essential for maintaining oral tissue health and for successful recovery after dental procedures. In particular, diabetes mellitus is associated with alterations in immune function, microvascular circulation, inflammatory responses, collagen metabolism, wound repair, and bone remodeling. These systemic and local changes may explain why patients with diabetes are more susceptible to periodontal disease, delayed healing after tooth extraction, postoperative complications, peri-implant inflammation, and impaired osseointegration [6–11,15–19,30,31,45–48].

One of the most consistently reported findings in the reviewed literature is the close relationship between diabetes mellitus and periodontal disease. Periodontal disease is among the most common oral complications observed in patients with diabetes and appears to be influenced by both the duration and degree of metabolic control. Diabetes may impair neutrophil function, alter the host inflammatory response, and promote vascular and connective tissue changes within the periodontium [15–18]. At the same time, persistent periodontal inflammation may contribute to deterioration of glycemic control, supporting the well-established bidirectional relationship between diabetes and periodontal disease [15–17]. Increased production of inflammatory mediators, including tumor necrosis factor alpha, interleukin-1 beta, and prostaglandin E2, may stimulate osteoclastic activity and contribute to progressive periodontal tissue destruction [18,19].

These findings indicate that periodontal assessment and treatment should form an integral part of the overall dental management of patients with type 2 diabetes rather than being considered an isolated dental issue. The findings concerning oral surgery are also clinically important. Patients with diabetes may experience delayed healing following tooth extraction because hyperglycemia interferes with angiogenesis, fibroblast proliferation, collagen synthesis, epithelialization, and immune defense [20–23]. Impaired vascularization and altered inflammatory responses may prolong the inflammatory phase of healing and interfere with normal regeneration of the extraction socket. These mechanisms may increase susceptibility to postoperative infection and other healing complications. The reviewed evidence therefore supports careful preoperative assessment and postoperative monitoring of diabetic patients undergoing dental extraction. Particular attention should be given to patients with inadequate metabolic control or other factors that may further compromise healing. Alveolar osteitis represents a clinically relevant postoperative complication in this population. The development of this condition may be influenced by impaired tissue repair, altered local vascularization, reduced host defense, and increased microbial activity within the extraction socket[21–24]. Recent work addressing regenerative approaches to the management of alveolar osteitis in patients with type 2

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diabetes further emphasizes the need for individualized postoperative protocols and appropriate local management [24]. Thus, prevention of postoperative complications should begin before surgery and continue throughout the healing period rather than being limited to treatment after complications have developed. The literature reviewed in this scoping review also supports the use of dental implants as an important option for rehabilitation of patients with type 2 diabetes mellitus. Tooth loss associated with periodontal disease and other oral complications can adversely affect mastication, nutrition, and quality of life, making implant-supported rehabilitation clinically valuable [25–29].

However, diabetes mellitus should be considered an important modifying factor when planning implant treatment. A systematic review by Wagner et al. demonstrated that diabetes, particularly when poorly controlled, may be associated with less favorable implant-related outcomes, while acceptable results can be achieved in appropriately selected and adequately controlled patients [26]. Other studies have similarly indicated that implant therapy should not be regarded as contraindicated solely because a patient has diabetes mellitus [27–29]. The biological basis for these findings is closely related to the effects of hyperglycemia on bone metabolism and osseointegration. Persistent hyperglycemia may suppress osteoblastic activity, increase osteoclastic bone resorption, interfere with collagen formation, and disturb normal calcium and phosphorus metabolism [30,31,45–48]. Diabetes-associated oxidative stress, chronic inflammation, and accumulation of advanced glycation end products may further impair bone remodeling and the formation of a stable bone-implant interface[30,31,45]. Consequently, inadequate metabolic control may delay osseointegration, reduce implant stability, and increase the possibility of implant-related complications.

The relationship between diabetes mellitus and peri-implant diseases is another important finding of this review. Evidence from systematic reviews and meta-analyses indicates that diabetes mellitus and hyperglycemia may be associated with an increased risk of peri-implantitis, although the strength of this association varies between individual studies [32–36]. Poor glycemic control appears to be particularly important, as elevated glycated hemoglobin levels have been associated with less favorable peri-implant clinical and radiographic parameters, including increased probing depth, bleeding on probing, and crestal bone loss [32,34]. Hyperglycemia may promote chronic inflammation, impair immune defense, increase oxidative stress, and interfere with bone remodeling, while dental biofilm may further stimulate an altered inflammatory response in susceptible patients [32–36]. Several additional factors should be considered when assessing the risk of peri-implant complications in patients with diabetes. Smoking, periodontal status, oral hygiene, glycemic control, and general metabolic status may all influence treatment outcomes [26,29,34–36]. A previous history of periodontal disease is particularly relevant because periodontal inflammation and inadequate plaque control may increase the risk of peri-implant inflammatory disease. In contrast, the available evidence is less conclusive regarding the independent influence of the duration of diabetes on implant failure [26]. Therefore, clinical decision-making should be based on an overall assessment of the patient's metabolic and oral condition rather than on the diagnosis of diabetes alone. An additional area of interest identified in this scoping review is the modification of implant surfaces. Contemporary implant research has investigated several approaches intended to improve bone formation and implant integration, including titanium surface modification, hydroxyapatite and calcium phosphate coatings, sandblasted large-grit acid-etched surfaces, anodic oxidation, and other surface treatments [37–39]. These approaches are designed to improve the interaction between the implant surface and surrounding biological tissues and may be particularly relevant in patients in whom bone healing is compromised.

Ultraviolet photofunctionalization represents a further development in this field. Studies have reported that ultraviolet treatment can alter the physicochemical properties of titanium surfaces, increase surface hydrophilicity, enhance osteoblast attachment, and promote early osseointegration[40–44]. The potential reduction in bacterial adhesion is also of interest in diabetic patients because impaired immune responses and altered tissue healing may increase susceptibility to peri-implant infection. Although these technologies are promising, their clinical effectiveness specifically in patients with type 2 diabetes mellitus requires further long-term investigation.

The findings concerning bone metabolism provide another potentially useful direction for individualized implant management. Diabetes mellitus may alter bone turnover and the activity of bone-forming and bone-resorbing cells, with changes in biochemical markers such as osteocalcin and beta-CrossLaps reported in diabetic populations [45–48]. Recent clinical research has also investigated bone metabolism markers in patients with type 2 diabetes receiving dental implants, suggesting that such biomarkers may provide additional information regarding bone remodeling and the biological response to implant treatment [49].

However, the clinical application of these markers as

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routine predictors of implant success remains insufficiently established and requires further prospective research. Vitamin D may also have an important role in the management of diabetic patients undergoing implant therapy. Vitamin D contributes to calcium and phosphorus homeostasis, bone mineralization, immune regulation, and bone remodeling [50–53].

Several studies have investigated the relationship between vitamin D status and implant healing, and some have suggested that correction of vitamin D deficiency may support bone formation and osseointegration [50–55]. The available evidence therefore provides a rationale for assessing vitamin D status in selected patients, particularly when deficiency is suspected or when additional risk factors for impaired bone healing are present. Nevertheless, vitamin D supplementation should be considered an adjunctive measure rather than a substitute for adequate glycemic control and appropriate surgical and periodontal management. Evidence concerning the broader metabolic effects of vitamin D supplementation remains heterogeneous [56,57]. From an organizational and methodological perspective, the reviewed evidence emphasizes that successful surgical dental care for patients with type 2 diabetes requires an individualized and multidisciplinary approach. Preoperative assessment should include evaluation of glycemic control, medical history, diabetes-related complications, current medication, periodontal condition, oral hygiene, and other relevant risk factors [58–63]. Dental treatment should be planned according to the patient's systemic condition, with appropriate preventive measures before and after surgical procedures. Long-term maintenance is particularly important for patients receiving dental implants because continued plaque control and professional monitoring may reduce the risk of peri-implant inflammatory complications [64].

The findings of this scoping review also demonstrate that diabetes mellitus should not be considered an absolute contraindication to surgical dental treatment or implant rehabilitation. Instead, the diagnosis should prompt more careful patient selection, assessment of metabolic control, prevention of infection, optimization of oral hygiene, periodontal management, and appropriate postoperative follow-up [26,29,58–64]. When these principles are followed, satisfactory clinical outcomes can be achieved in many patients with type 2 diabetes mellitus. At the same time, several limitations of the available evidence should be recognized. The studies included in the literature vary considerably in design, patient characteristics, definitions of glycemic control, implant systems, follow-up periods, and clinical outcome measures. This heterogeneity makes direct comparison between studies difficult. In addition, some aspects of surgical dental management in diabetic patients remain supported primarily by observational studies or limited clinical evidence. Further well-designed prospective studies with standardized definitions of glycemic control, peri-implant disease, bone turnover, and implant success are therefore needed. Overall, the evidence identified in this scoping review supports an integrated model of surgical dental care in patients with type 2 diabetes mellitus. Such an approach should combine metabolic assessment, prevention and treatment of periodontal disease, careful management of extraction wounds, individualized implant planning, attention to bone metabolism and vitamin D status where clinically appropriate, and long-term peri-implant maintenance. This integrated strategy may reduce complications and improve the predictability of surgical dental treatment in this growing patient population.

5. CONCLUSION

Patients with type 2 diabetes mellitus require individualized and multidisciplinary dental management because diabetes may influence oral health, wound healing, bone metabolism, osseointegration, and peri-implant tissue stability. The findings of this scoping review indicate that persistent hyperglycemia is an important factor contributing to periodontal inflammation, delayed healing after dental extraction, postoperative complications, impaired bone remodeling, and increased susceptibility to peri-implant diseases. Nevertheless, diabetes mellitus should not be regarded as an absolute contraindication to surgical dental treatment or dental implant therapy. Successful treatment is achievable when patients are appropriately selected and when glycemic control, periodontal health, oral hygiene, surgical planning, and postoperative maintenance are adequately addressed. Modern implant surface modification technologies may provide additional benefits for osseointegration, while assessment of bone metabolism and vitamin D status may contribute to more individualized treatment planning in selected patients. The evidence therefore supports a comprehensive organizational and methodological approach to surgical dental care in patients with type 2 diabetes mellitus. Such an approach should include preoperative medical and dental assessment, optimization of modifiable risk factors, prevention of postoperative complications, careful implant planning, professional maintenance, and long-term clinical monitoring.

Further prospective and long-term clinical studies are required to establish standardized protocols for surgical dental care, determine the predictive value of bone metabolism markers and vitamin D status, and clarify the long-term effects of glycemic control and implant surface

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modification on implant survival and peri-implant health in patients with type 2 diabetes mellitus.

DECLARATIONS

Ethical Approval

Not applicable.

Competing Interests

The authors declare no conflict of interest.

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