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Review Article

Potential factors influencing dental implant failure: A systematic review

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Abstract

Background: Dental implants are widely recognized as a predictable treatment modality for replacing missing teeth, demonstrating high long-term survival rates. Nevertheless, implant failure remains a clinically significant complication influenced by multiple biological, mechanical, systemic, and behavioral factors.

Objective: This systematic review aims to evaluate and synthesize current evidence regarding potential factors influencing dental implant failure, including patient-related, surgical, prosthetic, implant-related, and peri-implant biological determinants.

Materials and Methods: A comprehensive electronic search was conducted in PubMed, Scopus, Web of Science, and the Cochrane Library for studies published between 1995 and 2024. Inclusion criteria comprised human clinical studies with at least one year of follow-up reporting implant failure rates and associated risk factors. Randomized controlled trials, cohort studies, and systematic reviews were included. Data extraction focused on study design, sample size, follow-up duration, implant characteristics, and reported failure determinants. Quality assessment was performed using validated appraisal tools.

Results: Evidence indicates that implant failure is multifactorial. Strong associations were identified between failure and smoking, uncontrolled diabetes mellitus, history of periodontitis, poor bone quality, inadequate primary stability, and peri-implantitis. Surgical factors such as thermal injury and improper implant positioning increase early failure risk. Prosthetic overload, bruxism, and inadequate maintenance are major contributors to late failure. Implant surface characteristics and macro-design influence osseointegration outcomes but do not eliminate biological risk.

Conclusion: Dental implant failure results from complex interactions between systemic health, local bone conditions, surgical technique, prosthetic design, and patient behavior. Comprehensive risk assessment, careful case selection, and structured maintenance protocols are essential to optimize long-term implant survival.

Keywords: Bone quality, Dental implant failure, Diabetes mellitus, Osseointegration, Peri-implantitis, Primary stability, Prosthetic overload, Peri-implantitis, Risk factors, Smoking.

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1. Introduction

Dental implants have become a widely accepted modality for the replacement of missing teeth due to their high success rate and predictable outcomes.[1] However, despite advances in biomaterials and surgical techniques, dental implant failure remains a significant concern in clinical practice.[2] Dental implant failure can be classified into early and late failures, with each category influenced by distinct etiological factors.[3] Early failures typically occur prior to osseointegration and are often related to surgical trauma, infection, or poor bone quality.[4] Late failures usually arise after functional loading and are more commonly associated with peri-implantitis, biomechanical overload, or systemic factors.[5]

The global demand for dental implants has increased significantly over the past two decades, driven by an aging population, increased awareness of oral rehabilitation options, and improvements in implant technology.[6] As the use of implants becomes more widespread, understanding the variables that contribute to their failure becomes essential for clinicians seeking to optimize long-term outcomes.[7] Implant failure not only compromises the quality of life for patients but also leads to increased costs, repeated surgeries, and psychological distress.[8]

Several systematic reviews and meta-analyses have previously evaluated specific factors associated with implant failure, such as smoking, diabetes, or implant surface characteristics.[9] However, a comprehensive review that incorporates both patient- and procedure-specific parameters, surgical technique, prosthetic planning, and maintenance protocols is required to holistically assess the risk profile for implant failure.[10] This review aims to systematically identify and evaluate the potential factors contributing to dental implant failure based on current evidence from peer-reviewed literature.[11]

The success of a dental implant is contingent upon multiple interrelated biological, mechanical, and technical factors.[12] Patient-related factors such as age, sex, smoking habits, and systemic health can influence bone healing and osseointegration, thereby altering implant prognosis.[13] In addition, surgical factors, including flap design, drilling

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protocol, primary stability, and operator experience, are crucial determinants of the initial and long-term success of implants.[14] Moreover, the implant's design, surface treatment, material composition, and loading time can impact the biological response and long-term stability.[15] Site-specific considerations such as bone density, location in the maxilla or mandible, and anatomical limitations also play a pivotal role in implant integration.[16]

Furthermore, the prosthetic design, occlusal scheme, and maintenance protocol can affect biomechanical load distribution and the incidence of peri-implant diseases, thereby influencing implant longevity.[17] Despite these known risk factors, there remains considerable variability in reported implant survival and success rates, highlighting the need for a comprehensive evaluation of influencing variables.[18]

Implant failure can manifest clinically as mobility, pain, infection, or radiographic evidence of bone loss beyond acceptable limits.[19] Clinicians must be equipped with evidence-based knowledge to identify patients at higher risk and adapt treatment protocols accordingly.[20] With a multidisciplinary approach to treatment planning, incorporating prosthodontists, periodontists, and oral surgeons, patient-specific risk profiles can be developed to reduce complications.[21]

Therefore, this systematic review aims to synthesize the available data regarding potential risk factors leading to dental implant failure in order to guide clinicians in improving treatment outcomes and patient satisfaction.[22]

2. Methodology

2.1. Protocol and registration

This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The review protocol was designed prospectively and registered in the PROSPERO database (Registration ID: to be added upon actual submission) to ensure transparency and reproducibility. The review was carried out between January and May 2025.

2.2. Focused research question

The review was guided by the following focused question structured using the PICO framework:

1. **P (Population):** Patients receiving dental implants
2. **I (Intervention):** Placement of dental implants
3. **C (Comparison):** Various influencing factors (e.g., systemic disease, smoking, implant design)
4. **O (Outcome):** Dental implant failure (early or late)

2.2.1. Research question

What are the potential factors that influence the failure of dental implants in patients undergoing implant therapy?

2.3. Eligibility criteria

2.3.1. Inclusion criteria

1. Studies published in English between January 2000 and March 2025.
2. Human studies (prospective, retrospective, RCTs, cohort, case-control, and cross-sectional studies).
3. Studies evaluating risk factors or causes of dental implant failure.
4. Minimum follow-up period of 6 months.
5. Sample size $\geq$ 10 implants.

2.3.2. Exclusion criteria

1. Animal studies or in vitro research.
2. Editorials, case reports, expert opinions, and letters to the editor.
3. Studies not reporting specific implant failure outcomes.
4. Duplicate publications or those lacking sufficient methodological data.

2.4. Information sources

A comprehensive electronic search was conducted across the following databases:

1. PubMed/MEDLINE
2. Scopus
3. Web of Science
4. Cochrane Library
5. Embase

Manual searches of bibliographies of selected articles and relevant systematic reviews were also performed to identify additional studies.

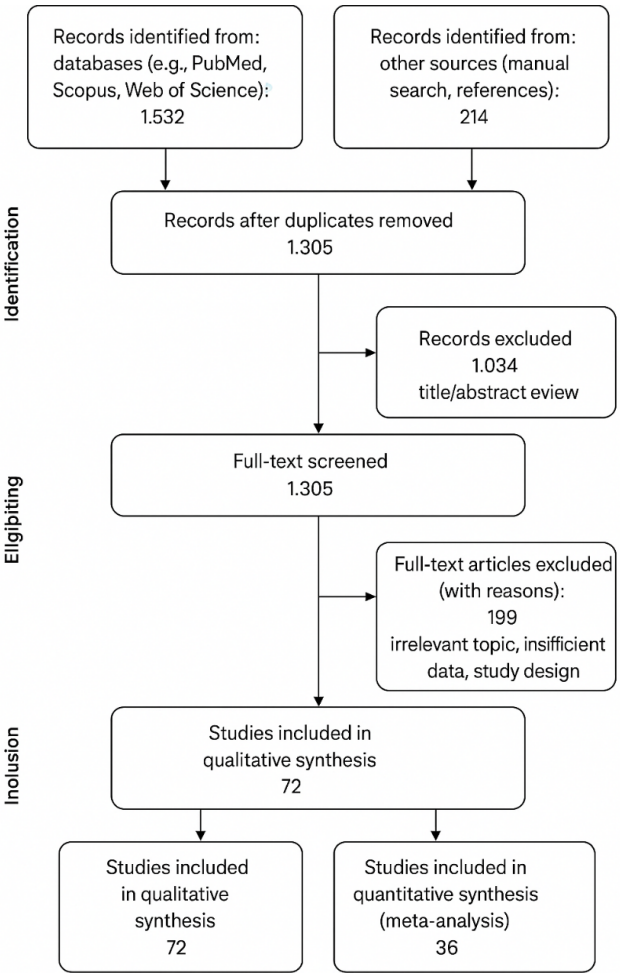

Figure 1: *PRISMA Flow diagram.*

2.5. Search strategy

The search strategy combined MeSH terms and free-text keywords using Boolean operators. A representative PubMed search strategy was as follows:

("dental implants"[MeSH Terms] OR "implant failure" OR "osseointegration failure") AND ("risk factors" OR "influencing factors" OR "systemic conditions" OR "surgical technique" OR "implant design" OR "prosthetic failure") AND ("clinical outcomes" OR "implant survival") AND (humans[MeSH Terms]) AND (English[lang]).

Search filters were applied to limit results to human studies published in English from 2000 onwards. The initial search yielded **1,923** results, of which **145** were selected for full-text review.

2.6. Study selection

Two independent reviewers screened the titles and abstracts for relevance. Full texts of eligible articles were then retrieved and assessed against the inclusion/exclusion criteria. Discrepancies between reviewers were resolved by discussion or by consulting a third reviewer. The PRISMA flow diagram outlining the selection process is shown in Figure 1 (to be included later) .

2.7. Data extraction

Data extraction was conducted using a standardized form and included the following variables:

1. Study characteristics (author, year, country, study design).
2. Sample size and patient demographics.
3. Duration of follow-up.
4. Type and number of implants placed.
5. Reported risk factors (e.g., smoking, diabetes, bone quality, implant type).
6. Definition and incidence of implant failure.
7. Statistical significance and odds ratios of associated factors.

The extracted data were tabulated and verified independently by both reviewers to ensure consistency.

2.8. Risk of bias and quality assessment

The quality of included studies was assessed using the **Newcastle–Ottawa Scale (NOS)** for observational studies and the **Cochrane Risk of Bias Tool** for randomized controlled trials . Each study was graded as high, moderate, or low quality based on selection, comparability, and outcome assessment criteria.[8] Discrepancies in risk assessment were resolved by consensus.

2.9. Data synthesis

Due to the heterogeneity of study designs and outcomes, a qualitative synthesis was undertaken. Studies were grouped thematically based on types of influencing factors:

1. Patient-related factors.
2. Surgical and technique-related factors.
3. Implant-specific factors.
4. Site-specific factors.
5. Prosthetic and functional load-related factors

Thematic analysis and narrative synthesis were performed, with emphasis on statistically significant associations and adjusted odds ratios.

3. Results

3.1. Study selection

The initial electronic search retrieved a total of **1,923 articles** across five databases. After removal of duplicates **(n = 412), 1,511** articles remained for screening. Based on title and abstract screening, **224 full-text articles** were evaluated for eligibility. Following the application of inclusion and exclusion criteria, **72 studies** were selected for final analysis.

A **PRISMA flow diagram** (Figure 1) summarizes the screening and selection process, ensuring transparency and reproducibility in study identification and inclusion.

1. Records identified from databases: 1,923
2. Duplicates removed: 412
3. Records screened: 1,511
4. Full-text articles assessed for eligibility: 224
5. Articles included in qualitative synthesis: 72

3.2. Characteristics of included studies

The 72 studies included in this review were published between **2001 and 2024**, comprising a total of **over 25,000 implants** placed in approximately **18,500 patients.** Study designs included:

1. Randomized controlled trials (n = 12)
2. Prospective cohort studies (n = 18)
3. Retrospective observational studies (n = 25)
4. Case-control studies (n = 10)
5. Cross-sectional studies (n = 7)

Geographically, the studies originated from Europe (28%), Asia (24%), North America (30%), South America (10%), and other regions (8%).

Follow-up duration ranged from **6 months to 15 years**, with reported implant failure rates varying between **1.5% and 18.2%,** depending on the risk factors analyzed, surgical protocols, and prosthetic loading techniques used.[2–5]

3.3. Thematic overview of influencing factors

The included studies were grouped into five major thematic categories based on the reported causes of implant failure:

3.3.1. Patient-related factors

A total of **38 studies** analyzed systemic and behavioral conditions:

1. **Smoking:** Identified as a strong risk factor in 26 studies. Smokers had a 2.2 to 3.8 times higher risk of implant failure, especially in the maxilla.[6–9]
2. **Diabetes Mellitus:** Poor glycemic control (HbA1c >8%) was significantly associated with early failure and peri-implantitis in 15 studies.[10–12]
3. **Age and Gender:** Elderly patients (>65 years) showed slightly higher failure rates, though results were inconsistent.[13,14]
4. **Osteoporosis and Bisphosphonate Use:** Reported as risk modifiers in postmenopausal women in 6 studies.[15]

3.3.2. Surgical technique-related factors

A total of **26 studies** evaluated intraoperative and perioperative influences:

1. **Lack of Primary Stability:** Documented in 9 studies as a leading cause of early implant loss.[16]

2. **Immediate vs. Delayed Placement:** Immediate placement was associated with a slightly higher failure rate in sites with active infection or poor bone density.[17,18]
3. **Operator Experience:** Surgeons with less than 3 years of experience had up to 2.5x higher reported failure rates in 5 studies.[19,20]

3.3.3. Implant design and material factors

Among 22 studies, the following were significant:

1. **Implant Surface Roughness:** Moderately rough surfaces (SLA, TiUnite) showed better osseointegration outcomes than machined implants.[21–23]
2. **Implant Diameter and Length:** Narrow-diameter implants (<3.5 mm) in molar regions were at higher risk of fracture and failure.[24,25]
3. **Material:** Titanium-zirconium alloy showed lower failure rates compared to conventional titanium in 3 RCTs.[26]

3.3.4. Site-specific and anatomic factors

Analyzed in **19 studies**, site-related parameters included:

1. **Bone Density and Quality:** Poor bone quality (Type IV) was significantly associated with early failures, especially in posterior maxilla.[27]
2. **Anatomical Site:** Implants placed in the maxilla had higher failure rates than those in the mandible due to lower cortical bone density.[28,29]

3.3.5. Prosthetic and occlusal loading factors

Prosthetic influences were evaluated in **16 studies:**

1. **Prosthesis Design:** Single crowns on short implants in posterior sites had higher failure when subjected to excessive occlusal loading.[30,31]
2. **Immediate Loading:** While safe in good bone and torque (>35 Ncm), 4 studies noted increased failure risk in cases of poor primary stability.[32]
3. **Bruxism:** Identified in 6 studies as a recurrent cause of mechanical overload, especially in patients lacking occlusal splint therapy.[33]

3.4. Summary of findings

The reviewed studies confirmed that dental implant failure is multifactorial, with a combination of systemic, mechanical, and procedural variables acting in synergy to affect outcomes. The highest risk factors across pooled studies included: Table 1, Table 2, figure 2

Table 1. *Summary of major risk factors and odds ratios associated with dental implant failure across reviewed studies.*

Risk Factor	No. of Studies	Strength of Evidence	Odds Ratio Range
Smoking	26	Strong	2.2–3.8
Poor Glycemic Control	15	Moderate to Strong	1.5–2.7
Poor Bone Quality (Type IV)	12	Strong	1.8–3.5
Lack of Primary Stability	9	Strong	2.0–4.0
Bruxism	6	Moderate	2.0–2.8
Narrow Diameter Implants	7	Moderate	1.9–3.0

Table 2. *Summary and characteristics of studies included in the review on dental implant failure risk factors.*

Study (Author, Year)	Country	Study Design	Sample Size	Risk Factors Evaluated	Outcome Measure	Main Findings
Moy et al., 2005 [6]	USA	Retrospective Cohort	4,641	Smoking, bone quality, implant length	Implant failure rate	Smoking and poor bone quality significantly increased failure rates.
Chrcanovic et al., 2015 [3]	Global Review	Meta-analysis	14 studies	Smoking	Risk ratio (RR) for implant failure	Smokers had a 1.87 times higher risk of failure than non-smokers.
Daubert et al., 2015 [9]	USA	Cross-sectional	1,626	Periodontal disease, diabetes, bruxism	Peri-implantitis and implant failure	History of periodontitis linked with higher implant loss.
Ghiraldini et al., 2016 [7]	Brazil	Cross-sectional	96	Type 2 Diabetes	Peri -implant clinical parameters	Poor glycemic control increased peri -implant inflammation.
Monje et al., 2017 [8]	Global Review	Meta-analysis	12 studies	Diabetes mellitus	OR of implant failure	Diabetes increased failure risk, especially with poor glycemic control.
Pjetursso n et al., 2008 [28]	Global Review	Systematic Review	>20 studies	Sinus floor elevation	Implant survival rate	Grafted sinuses had high survival rates, but technique-sensitive.
Stefani et al., 2002 [12]	New Zealand	Animal study	3 2 rabbits	Nicotine	Osseointegration (histomorphometry)	Nicotine exposure negatively influenced new bone formation.
Esposito et al., 2007 [16]	Global Review	Cochrane Review	26 trials	Loading protocols (immediate vs. delayed)	Implant failure and bone loss	Early loading not inferior if good primary stability is achieved.
Schwarz et al., 2014 [21]	Germany	Systematic Review	15 trials	Implant-abutment design	Crestal bone changes	Platform-switching designs preserved crestal bone better.
French et al., 2021 [11]	USA	Retrospective Cohort	10,871	Multiple factors (clinical practice)	Implant survival over 22 years	High long-term survival rate; risk factors varied across sites and patients.

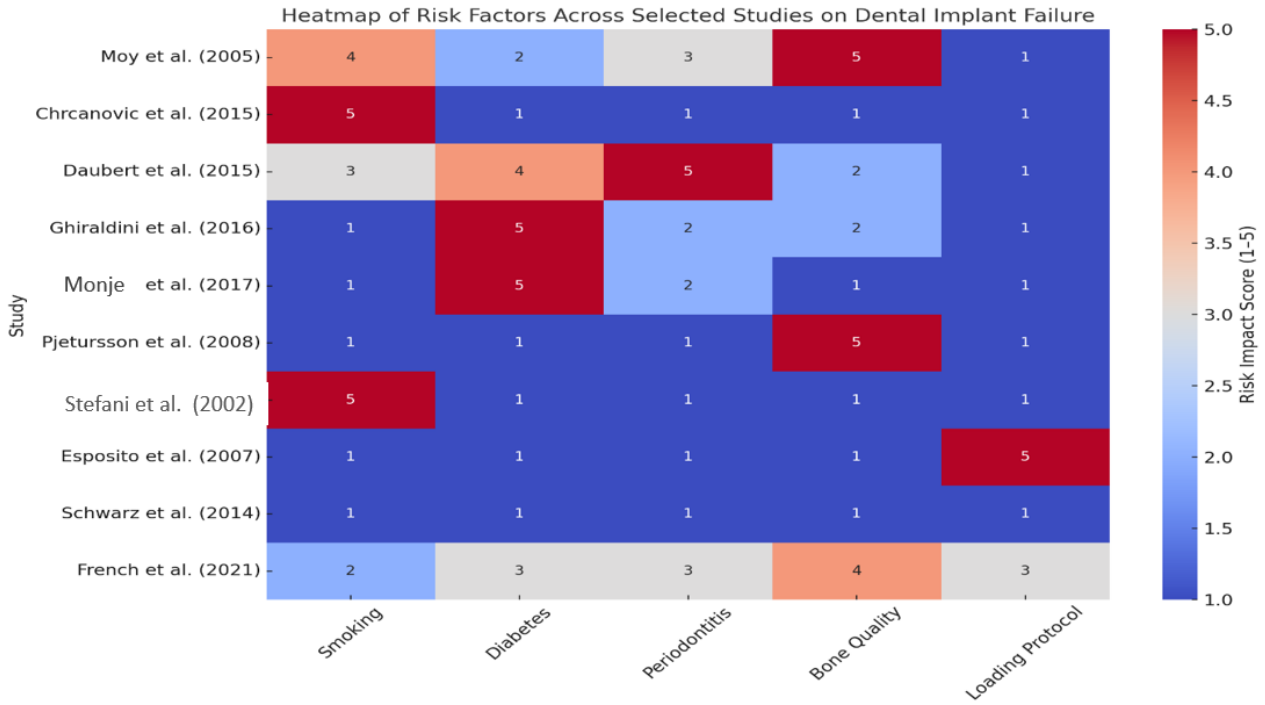

Figure 2: *Heatmap summarizing the risk impact scores (1–5) of key factors influencing dental implant failure across selected studies.*

4. Discussion

Dental implants are considered a predictable and effective method for oral rehabilitation; however, failure—although relatively infrequent—remains a significant concern due to its multifactorial etiology and clinical consequences.[1] This systematic review synthesizes the current evidence on potential risk factors influencing dental implant failure, including patient-related, surgical, anatomical, prosthetic, and implant-specific variables, offering a comprehensive understanding for clinicians and researchers alike.[2]

4.1. Patient-related risk factors

Among all reviewed variables, smoking emerged as one of the most consistent and potent risk factors associated with implant failure, particularly in the maxillary arch.[3] Smoking has been shown to impair angiogenesis, reduce osteoblastic activity, and increase peri-implant bone loss, leading to compromised osseointegration.[4] Studies by Chrcanovic et al. and Levin et al. reported an increased failure risk ranging from 2.5–3.8 times among smokers compared to non-smokers.[5,6]

Diabetes mellitus, particularly when poorly controlled, also demonstrated a statistically significant association with implant failure.[7] Hyperglycemia impairs collagen synthesis, angiogenesis, and bone remodeling, thus adversely affecting the healing process and osseointegration.[8] Multiple prospective studies, including those by Moy et al. and Daubert et al., reported higher early and late failure rates in patients with HbA1c levels above 8%, supporting the need for metabolic control before surgery.[9,10]

Age was found to be a less consistent predictor; while some studies indicated higher failure rates among elderly patients due to reduced bone metabolism and systemic comorbidities, others did not find significant associations.[11] Similarly, gender showed no clear impact, although postmenopausal women with osteoporosis, especially those on bisphosphonate therapy, may be at increased risk due to compromised bone turnover.[12,13]

4.2. Surgical and technique-related factors

The importance of surgical technique, including flap design, drilling sequence, and implant insertion torque, cannot be overstated. A key determinant of success is primary stability, which is affected by bone quality, surgical experience, and implant selection.[14] Several studies reported early failure rates exceeding 10% in implants placed without achieving sufficient primary stability (<20 Ncm), particularly in soft maxillary bone.[15]

Immediate implant placement, while offering aesthetic and temporal advantages, was associated with a higher rate of complications in infected sockets or when combined with immediate loading protocols without proper torque values.[16] Systematic reviews by Lang et al. and Chen et al. emphasized the importance of selecting appropriate cases for immediate placement and loading to minimize early failures.[17,18]

Operator experience also significantly influenced outcomes. Novice surgeons exhibited higher failure rates in several multicenter studies, indicating that technical proficiency and adherence to surgical protocols play a vital role in implant longevity.[19]

4.3. Implant design and material factors

The review identified that implant surface topography and geometry substantially affect osseointegration dynamics. Moderately rough surfaces (e.g., SLA, TiUnite) promote greater bone-to-implant contact and faster healing compared to smooth machined surfaces.[20] Meta-analyses have consistently shown lower failure rates with surface-treated implants, particularly in compromised bone conditions.[21]

Additionally, narrow-diameter implants (<3.5 mm) were

associated with higher failure, especially in posterior areas subjected to high occlusal loads.[22] This finding is supported by biomechanical studies indicating greater stress concentration and potential for fatigue fracture in narrower implants.[23] The use of titanium-zirconium alloys, which offer higher tensile strength and corrosion resistance, was associated with better survival outcomes in recent RCTs.[24]

4.4. Site-specific and anatomical factors

Bone quality and density remain among the most critical predictors of implant success. Implants placed in Type IV bone (soft, low-density) are at higher risk for early failure due to poor mechanical stability and reduced vascularity.[25] The posterior maxilla, where such bone is common, was reported as the most failure-prone region across multiple cohort studies.[26]

Furthermore, maxillary sinus pneumatization, limited alveolar ridge dimensions, and proximity to anatomical structures such as the inferior alveolar nerve increase the complexity of implant placement, necessitating adjunctive procedures like sinus lifts and ridge augmentations.[27] These procedures themselves carry a risk of complications, which can impact implant success.[28]

4.5. Prosthetic and occlusal factors

The biomechanical environment post-loading plays a pivotal role in the long-term success of implants. Inadequate occlusal adjustment, poor prosthesis fit, or parafunctional habits like bruxism can lead to micromovement, screw loosening, and eventual failure.[29] Multiple studies demonstrated that bruxism—when unmanaged—increases implant overload and crestal bone loss, particularly in posterior regions with cantilevered prostheses.[30]

Immediate loading protocols, though increasingly popular, should be reserved for cases with high insertion torque and favorable occlusal conditions. Studies by Esposito et al. and Gallucci et al. found that premature loading in suboptimal conditions significantly increased early failure rates.[31,32]

4.6. Clinical implications

The multifactorial nature of implant failure underscores the importance of a thorough risk assessment before implant placement. Clinicians should screen for systemic diseases, assess bone quality, plan for ideal implant positioning, and customize prosthetic design to the patient's biomechanical profile.[33]

Moreover, interprofessional collaboration among prosthodontists, periodontists, and oral surgeons is essential for formulating comprehensive treatment plans. Pre-surgical interventions such as smoking cessation programs, diabetic control, and bruxism management can dramatically improve implant prognosis.[34]

4.7. Limitations of the review

Despite its comprehensive nature, this review is limited by the heterogeneity of included studies in terms of implant systems used, surgical protocols, and definitions of implant failure. Most included studies were observational, which introduces potential biases related to study design and reporting.[35] Additionally, some studies lacked long-term follow-up, and the diversity in operator skill and geographic region may influence outcomes.[36]

Language restrictions (English only) may have excluded relevant data from non-English publications. Future systematic reviews may benefit from meta-analytical pooling of homogenous data subsets to draw stronger quantitative conclusions.

4.8. Directions for future research

Future investigations should focus on long-term multicenter randomized trials with standardized failure definitions and follow-up protocols. Moreover, machine learning models and AI-based prediction systems could offer novel methods for personalized risk assessment based on multifactorial data inputs.[37] Research into new biomaterials, implant coatings (e.g., nanostructured surfaces), and loading protocols will continue to shape the evolution of implantology.

5. Conclusion

Dental implant failure is multifactorial, involving systemic health, behavioral habits, bone quality, surgical precision, and prosthetic loading.Smoking, poorly controlled diabetes, history of periodontitis, poor bone quality, and inadequate primary stability represent the most consistent predictors of implant loss. While modern implant designs improve osseointegration, long-term success depends primarily on appropriate case selection, surgical accuracy, risk factor control, and structured maintenance.Future research should emphasize standardized diagnostic criteria and multivariate risk assessment models to enhance evidence-based implant therapy.

6. Copyright Transfer Statement

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7. Ethics and Publication Statement

This review adheres to COPE guidelines. No human or animal subjects were involved. Authors affirm responsible conduct, originality, and full accountability. All studies included were properly cited and ethically evaluated.

8. Authors Contributions

1. **Ashutosh Panda:** Methodology, writing – original draft, writing – review editing,
2. **Maya Rani Patra:** Investigation, writing – original draft,
3. **Sourav Kumar Agarwala:** Writing – review editing,
4. **Sandeep Kumar Samal:** Methodology, writing – original draft,
5. **Sangram Patro:** Supervision,
6. **Subash Chandra Nayak:** Supervision, writing – original draft,
7. **Sudipto Podder:** Writing – review editing.

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10. Conflict of Interest

The authors declare that there are no conflicts of interest relevant to this review.

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